NMR05A223

N223

207B . NMR05A223 0001
MOLYCORP INC - MOLYCORP QUESTA MINE
QUESTA NEW MEXICO 38755

$00240544

Rec#240527 /WA/NP/SE/

ARR1-626901917

3-4-13-1 FTW-01-01-023-2-013-07-006

Transfer#: F412-07-0026 **Box:**7 **CC:**R6

Asset#: %00930250 **Whole Container:** N

C/F: NMR05A223 VOL 1 MOLYCORP QUESTA MINE $0 **Created:** 3/1/2013

THOUSE General Reference Temporary Loan of Records

Standard Other (contact FRC to arrange) BILL OUR UPS ACCOUNT

To: PATRICIA VINCENT
EPA / DALLAS , 1445 ROSS AVE., SUITE 1200
DALLAS, TX, 75202
P : (214) 665-6532 F :

9389759

NMR05A223 Post Mark 8/29/97 SIC 1061 Sample 3 0.0 Acre
MOLYCORP INC Start Const.
PO BOX 469 End Const.
QUESTA, NM 87556- Terminated
MOLYCORP QUESTA MINE N Y
4 MI E OF QUESTA ON HWY 38
QUESTA NM 38755-6
DAVID R SHOEMAKER 8/29/97 (505) 586-7601
364110 1053140
PPP Likeli Endgrd PartIBJe FDORL
Ferroalloy Ores, Except Vanadium

DUPLICATE
STUDIES

TRC *Environmental Solutions Inc.*

GEYZA I. LORINCZI

APR 30 1997

QUESTA MINE SITE EXPERT REPORT

Prepared by

Ian P.G. Hutchison

April 23, 1997

QUESTA MINE SITE
EXPERT REPORT BY IAN P.G. HUTCHISON

I, Ian P.G. Hutchison, Senior Vice President of TRC Environmental Solutions, Inc., have been retained to provide the following expert report in *Amigos Bravos and New Mexico Citizens for Clean Air vs. Molycorp, Inc.* (D.N.M. No. CIV 95-1497 [JP/DJS]).

1.0 SUMMARY OF QUALIFICATIONS

1.1 GENERAL QUALIFICATIONS

- Senior Vice President of TRC Environmental Solutions, Inc., with general responsibilities for mining environmental, and Superfund remediation projects.
- Over 25 years of experience in dealing with water quality issues at a large number of mining and industrial sites in the United States, Canada, South America and Africa.
- Ph.D. in Civil Engineering and Graduate Diploma (M.S. equivalent) in Hydraulic and Soil Mechanics from the University of the Witwatersrand, South Africa, and a B.S. in Civil Engineering from the University of Cape Town, South Africa.
- Experience on over 50 mining environmental projects throughout the United States, Canada, South America and Africa.
- Registered Professional Engineer in eight states, including New Mexico.
- Resume is provided in Attachment A.

1.2 PUBLICATIONS

- Senior editor and author of a textbook entitled "Mine Waste Management" published in 1992, Lewis Publishers.
- Other publications in the last 10 years include:
  - *Introduction to Evaluation, Design and Operation of Precious Metal Heap Leaching Projects*, Editor and Author of Chapter on "Surface Water Balance," 1988.
  - *Management for Hazardous Waste Liability at Mining Sites.* Colorado State University Symposium, January 1991.
  - *Summitville Mine - Remedial Alternatives Identification and Evaluation.* I.P. Hutchison, Michael L. Leonard, Sr. and David P. Cameron. Summitville Forum 95: A Forum held in Conjunction with Tailings and Mine 1995, Colorado State University, Fort Collins, Colorado, January 1995.

1.3 CASES IN THE LAST FOUR YEARS

- Involved as an expert witness and provided deposition or trial testimony on the following cases in the last four years:
  - *IMACC vs. Dorothy Myers Warburton, et al.*
  - *Penny Newman et al. versus State of California, Riverside County, et al.* regarding the Stringfellow site, California, 1993.

1.4 COMPENSATION

- My hourly rate is $160/hour.

2.0 SUMMARY OF OPINIONS

1. My major opinions deal with the diffuse nature of the sources of constituents, the seepage and ground water flow conditions at the mine site, and the surface water quality conditions in Red River. Naturally occurring alteration minerals occur within bedrock dispersed throughout the fractured bedrock area, are exposed on the surface in weathered bedrock (referred to as natural scar areas), and are dispersed within the colluvium and alluvium, and throughout most, but not all, of the excavated overburden pile material. Oxidization and weathering primarily of one of the minerals present, i.e., pyrite, can cause acidic conditions (i.e., low pH) and contribute dissolved constituents, which include a range of salts and metals, to surface or ground water flow that comes into contact with the weathered minerals. References in this report to "constituents" implies generally one or more substances from the range of salts and metals which typically include total dissolved solids (TDS), sulfate, aluminum, cadmium, copper, iron, manganese and zinc.

2. More specifically, my opinions are:
   - **Constituent Sources and Conveyances:** There are no discernible, confined and discrete conveyances of constituents from the overburden piles (also referred to as waste rock piles) to the Red River.
   - **Hydraulic Connection:** Conditions at the mine site are not well enough understood to determine whether there is a direct hydraulic connection between the overburden piles and Red River.

- **Red River Water Quality:** The available data does not support the conclusion that there has been a general reduction in the water quality of the Red River caused by mining activities between the mid-1960s and the mid-1990s.
- **Source of Constituents in Red River:** The available data does not allow for a determination of whether constituent loadings in Red River are derived from overburden piles, scar areas, or from alluvial deposits in tributary and Red River channels.

3. In addition to the above opinions, I have reviewed the plaintiff's expert reports and have provided comments on them.

4. The remaining sections of this report deal with the following topics:
   - 3.0 Basis for Major Opinions
   - 4.0 Summaries of Comments on Plaintiffs' Expert Reports

3.0 BASIS FOR MAJOR OPINIONS

3.1 CONSTITUENT SOURCES AND CONVEYANCES

1. There are no discernible, confined and discrete conveyances of constituents from the mine's overburden piles for the following reasons:
   - **Diffuse Sources:** Migration of water and constituents from and through the overburden piles is diffuse.
   - **Diffuse Flow Paths:** Migration of water and constituents through the alluvium and fractured bedrock, which underlie the overburden piles, is diffuse.
   - **Seepage Zones:** Migration of water and constituents into Red River, including the springs, which are actually seepage zones, is diffuse.

2. Each of these reasons is discussed in more detail below.

3.1.1 DIFFUSE SOURCES

1. The primary source of constituents in the overburden piles is the acid-generating minerals that are attached to the soil particles and boulders. Both water and oxygen are necessary to cause these minerals to oxidize or weather. This process can cause acidic conditions (i.e., low pH) and dissolves the constituents contained in the minerals. Infiltration of water during rainstorms and snowmelt migrates generally downward through the piles and dissolves the constituents. Infiltration is typically widespread over the surfaces of the piles; however, the rates of infiltration vary at different locations on the piles, depending on the surface slope and the amount of clay and silt present.

2. To the extent they represent potential sources of constituents, the overburden piles, therefore, are widespread diffuse seepage sources, with the amount of constituent loading varying within the source area.

3.1.2 DIFFUSE FLOW PATHS

1. Migration of water and constituents (or seepage) from the piles continues downward through the underlying unsaturated alluvium, natural hydrothermal scar areas, and/or fractured bedrock above the ground water table. Some lateral spreading may occur on lower permeability layers within the waste piles, or the underlying alluvium, or on low permeability bedrock surfaces. Migration of this widespread diffuse source therefore continues to be neither discernible, confined nor discrete. It is generally not discernible as it occurs as a subtle increase of moisture content on the surface of soil particles and in the large number of interconnected fractures that occur in bedrock. It is unbounded as it occurs over a widespread area, and finally, it is not discrete as it occurs in millions of pores and fractures in the soils and bedrock.

2. The alluvial material that occurs at the site is typically sandy, silty and sometimes clayey material. Ground water migration through these soils is diffuse, but rates of migration will vary locally depending on the soil types and composition.

3. After passing through the unsaturated zone, seepage from the overburden piles is mixed with ground water and then continues to migrate slowly through alluvium and fractured rock to deep bedrock below the Red River, to the Red River, or into the dewatered underground mine workings by the same diffuse flowpaths described above.

4. The geology of the area is complex, and a large number of faults and structural fractures have been identified at the site (SPRI, 1995). These include:
   - East-west trending low angle (relatively flat) faults and structural contacts dipping to the north;
   - High angle east-west, northeast and northwest trending faults;
   - Other high angle joints and fractures;
   - High and low angle fractures adjacent to magmatic intrusions.

   Typically, faults include zones of more permeable fractured rock as well as zones of low permeability rock where clayey materials can be present, where the fault zones "pinch out," or where faults are offset by younger faults cutting across older faults.

5. In addition to this largely random distribution of more permeable to less permeable zones formed by the faults described above, the bedrock between the faults is also highly fractured. Fractures occur at a large number of different orientations and typically have a large range of lengths and thicknesses. The intersection of these fractures and the faults causes the millions of migration pathways referred to in paragraph 1 above.

6. Ground water located in the fractured bedrock acts like water in a very large sponge, with a very large number of interconnected openings of varying size. Because of the random nature of the large number of faults and fractures in the bedrock, the rate of ground water migration can vary considerably from one area to the next.

7. Published ground water flow theories frequently treat flow through "fractured rock" as a diffuse flow through a continuum, which approximates flow through a porous medium (such as silt or sand) with increasing size of areas that are being analyzed. Due to the large size of

the mine facilities, and the mine site area, ground water migration could be analyzed as flow through porous media (Hubbert, 1956; Long et al., 1982; Hsieh et al., 1985).

8. As seepage containing dissolved constituents derived from the overburden piles migrates downgradient and away from the piles, the constituent concentrations are typically reduced by their contact with unmineralized alluvium and fractured bedrock, particularly if the alluvium or bedrock has the potential to neutralize acidic water. This process is referred to as attenuation and includes a combination of dilution, precipitation, adsorption and complexation. Metals are most susceptible to attenuation; however, salts can also be attenuated.

9. Furthermore, as ground water migrates through naturally acid-generating mineralized bedrock underlying the scars or alluvium that consists of eroded and redeposited scar material, additional salts and metals can be dissolved, leading to increased constituent concentrations.

10. It is evident that the concentration of constituents in ground water is not only a function of the source concentrations, but also the chemical interactions that occur within the ground water as it migrates through alluvial and fractured bedrock material. As a general rule, the further the ground water migrates from the original source of constituents, the less the constituent concentrations are dependent on that source, and the more they are dependent on the natural properties of the alluvium and fractured bedrock.

3.1.3 SEEPAGE ZONE

1. Referring to the seepage through the banks of the Red River as "springs" is inaccurate:

   > *"A spring is a concentrated discharge of ground water appearing at the ground surface as a current of flowing water. To be distinguished from springs are seepage zones, which include slower movement of ground water to the ground surface."* (D.K. Todd, 1980)

2. It is more appropriate to use "seepage zones" to describe the areas along the banks of Red River, such as Capulin, Portal and Cabin Spring. This is based on my field observations and field mapping of seep areas conducted by GSi/water (GSi, 1997). It is also supported by Dr. Mink's expert report (Mink, 1997) and by deposition statements by both Dr. Mink and

Mr. Kelsey (Mink deposition, 1997; Kelsey deposition, 1997). These seepage zones have the appearance of wet soils or shallow fractured bedrock with water seeping out of the pore spaces at a varying rates throughout the seepage zone.

3.2 HYDRAULIC CONNECTION

1. Conditions at the mine site are not well enough understood to determine whether there is any direct hydraulic connection between the overburden piles and the Red River. It is virtually impossible to determine how much, if any, of the constituents emanating from the overburden piles migrate to the river, for the following reasons:
   - **Alternative Diffuse Migration Pathways:** There are several diffuse migration pathways for seepage derived from the overburden piles, including migration out of the general area in deep faults and fractures located well below the bed of the Red River and migration into the underground mine workings.
   - **Geochemical Processes:** The chemical reactions that take place as migration occurs alters the concentrations of the constituents and retards or eliminates the potential direct migration of constituents from the overburden piles to the Red River. As discussed below, this phenomenon is illustrated by the fact that the Red River reach along and closest to the largest overburden piles in the mine site area receives a lower mass TDS loading than river reaches adjacent to areas containing natural scars located close to the river, or adjacent to the town of Red River (Figure 6).
   - **Mixed Sources:** Because there are a large number of mining related sources (overburden piles) and nonmining related natural sources (scars, mineralized fractured bedrock, and mineralized alluvium) it is essentially impossible to distinguish whether any particular constituent loading to Red River is due to either natural or mine-related sources.

2. Each of the above reasons is discussed in more detail below.

3.2.1 ALTERNATIVE DIFFUSE PATHWAYS

1. As discussed above, the three potential diffuse migration pathways for seepage from the overburden piles include migration in deep bedrock faults and fractures to the west and below the Red River, migration into the underground mine, and shallow migration to the Red River.

2. While it is generally true that fractured bedrock permeability decreases with depth, the depths at which significant decreases occur vary from site to site. Evidence at the Questa Mine site indicates permeable bedrock occurs at considerable depths, and deep migration pathways are therefore very likely. This evidence includes:

   - During geologic time the area was subjected to extensive volcanism related to regional continental rifting. The major structural features, such as the high angle ring faults surrounding the caldera in which the mine is situated, are likely to be several thousands of feet deep. In addition, subsequent intrusions such as dikes and plutons derived from subterranean magma chambers and their associated fracturing, also extend to a great depth. The thickness of intra-caldera volcanic units are reported to range up to 10,000 feet in the Questa Caldera (SPRI, 1995), which would be the minimum depth of the above referenced high angle ring faults and subsequent intrusive structures. Figure 1 illustrates the typical structure for a caldera similar to the Questa caldera. Figure 2 shows the outline of the Questa caldera including the major faults that have been mapped or otherwise inferred in the area.
   - Water is observed by Molycorp personnel to seep into the deep underground mine workings through a large number of faults and fractures. The so-called "rain forest" occurs deep in the underground mine along the haulage drift at elevation 7,120 which is 600 to 700 feet below the level of the Red River and over 2,000 feet below the ground surface. Molycorp's underground mine mapping shows that extensive fracture systems are still present at this depth and represent a source of seepage into the mine (Molycorp, 1997).

3. As mentioned above, and as shown in Figure 3, the underground mine workings create a large drawdown cone in the ground water table which intercepts infiltration at the mine site, and seepage from the overburden piles. The interpretation in Figure 3 of the ground water levels in the mine area is the most reasonable given the available monitor well ground water level data; it also incorporates the Red River water levels. The mine's ground water capture zone estimated from these ground water contours is in general agreement with that determined by SPRI (SPRI, 1995, Figure 8) in that it shows capture extends from the Goathill Creek area in the west, to the area under the Sugar Shack, South Middle and Sulfur Gulch overburden piles to the east.

4. In my opinion the most realistic assessment of the average recharge from ground water in the mine area is SPRI's estimate of 0.66 cfs, or 295 gpm which is based on long term (1943 to 1955) base flow data for the general area between the Zwergle gauge upstream of Red River

and the Ranger Station gauge near Questa (SPRI, 1995, page B-6). It has been calculated for a mine site drainage/catchment area of approximately 3,200 acres, which includes portions of Capulin Canyon and Spring Gulch drainage areas that are outside of the projected capture zone for the mine. The other estimate presented in SPRI's report (SPRI) uses assumptions as to the amount of infiltration which appear to be too high, and which are not as reliable as the data-based estimate.

5. The SPRI estimate of average recharge is also appropriate for the 1980s to the 1990s. The average Red River flow at the Questa gauge was 48.6 cfs for the period 1943 to 1955, for which the above recharge estimate was performed. The flow during this period is close to the average flow at Questa during the 1980s and 1990s, i.e., 50.8 cfs for 1980 through 1993.

6. Correcting the SPRI's estimate for the area captured by the underground mine workings, which is approximately 2,300 acres (Attachment C), yields a ground water recharge rate of about 210 gpm.

7. Accounting for the increases in surface flows to the underground mine caused by the diversion of the upper portions of the Capulin Canyon and Goathill Creek Drainages (approximately 585 acres), and of surface water collecting in the open pit area (575 acres) yields approximately an additional 103 gpm (Attachment C, Table 1). This means that on the average, approximately 313 gpm, including the diversions and open pit, infiltrate in the underground mine's capture area.

8. Molycorp's reported equilibrium pumping rate from the underground workings is 270 gpm (Molycorp, 1997). To this amount should be added any seepage that occurs out of the mine through deep fractures. As the typical level of accuracy of these types of calculations is of the order of 20 percent, the over 270 gpm from the underground mine and the 313 gpm total infiltration may be treated as the same values. This indicates that virtually all the ground water flow in the mine's capture area is being pumped out of the area and does not migrate to Red River.

9. The estimated underground mine workings cone of depression captures seepage from the Capulin Canyon, Goathill Creek, and Sugar Shack West overburden piles, most of the western potions of the Sugar Shack South and Middle, and Sulfur/Spring Gulch piles and the open pit

overburden disposal piles (Figure 3). The only overburden that appears to be outside of the capture area is the Spring Gulch pile, and the limited eastern portions of the Sugar Shack South, Middle and Sulfur/Spring Gulch piles. The potential for seepage of constituents from the Spring Gulch overburden pile to Red River is very limited, based on evaluations and testing conducted by SRK, it contains black andesite, aplite and granite; *"These materials exhibit an average net neutralization potential. The average NP/AP ratio for black andesite and aplite/granite exceeds 3:1, indicating low acid producing potential."*

10. The potential for seepage of constituents from the Sulfur/Spring Gulch pile is also very limited because the eastern portion of this pile projected outside the underground mine capture zone, contains nonacid-generating black andesite and aplite/granite (SRK, 1995, page 33). Furthermore, the potential for seepage of constituents from this pile may be further reduced by the decline, which is a downward sloping tunnel that passes under the Sulfur/Spring Gulch pile and which could be intercepting ground water seepage from that pile. SRK in their report (SRK, 1995, page 29) indicate that ground water seepage occurs into the decline. Plaintiffs' expert Dr. Mink (Mink deposition, 1997, page 135) concurs that the decline may be dewatering ground water in the vicinity of monitoring well MMW-14 and -16, along the eastern edge of Sulfur/Spring Gulch pile.

11. The potential for seepage of constituents to Red River from the eastern portions of Sugar Shack South, Middle, and Sulfur/Spring Gulch piles is further reduced because the eastern faces of these piles have been covered with nonacid-generating black andesite and aplite/granite (SRK 1995, page 33).

3.2.2 GEOCHEMICAL PROCESSES

1. As previously mentioned, seepage containing constituent concentrations is subject to attenuation by the alluvium and fractured bedrock through which it migrates. Evidence that a significant amount of attenuation capacity exists in the fractured bedrock is the quality of the underground mine water. As discussed by SRK (SRK, 1995, page 27 and Table 1.4), the water pumped out of the mine is characterized by neutral pH, high TDS and sulfate and reduced metal concentrations, typical changes that occur during attenuation.

2. Further support for the presence of the natural attenuation capacity of the fractured bedrock is found in the inherent characteristics of the rocks in the area. The abundance of alkaline and calc-alkaline volcanic host rocks, such as aplite, latite, and dacite, and the added presence of natural carbonate alteration products in mineralized zones, provide natural neutralization capacity for migrating acidic water. Secondary alteration minerals, such as gypsum, provide additional neutralization capacity. The erosion and deposition of these materials in the valley fill alluvial deposits as cementation agents or detritus also provide neutralization capacity.

3. While SRK (SRK, 1995) indicates the alluvium has a limited neutralization potential, its samples were limited to three locations (Nos. 86, 88 and 94, Figure 3.3, SRK, 1995). Two of these samples (i.e., 86 and 88) could have been collected from alluvial material derived at least partly from the erosion of natural scar material. None of these samples are representative of the fractured bedrock under the overburden piles, which is where most of the seepage from these piles would go, nor are they representative of the alluvium along Red River.

3.2.3 MIXED SOURCES

1. As discussed above, there are a number of natural and mining related sources of constituents. They not only include the scar areas and overburden piles, but also generally mineralized acid-generating areas such as the lower Capulin Creek area (SRK, 1995), and alluvium derived from eroded scar material that has been deposited in the tributary creekbeds as well as the bed and banks of the Red River. Evidence for the presence of mineralized material in the creekbeds is also provided by some of the soil samples collected by SRK (Samples 10, 69, 70, 73, 87, HC6, and HC7; SRK, 1995). Furthermore, ground water in the alluvium south of Red River (i.e., on the opposite side of the river from the mine site) has a low pH (GSi, 1997), which provides more evidence of potential acid-generating mineralized material along the Red River.

2. The alluvium was placed in the creek and Red River beds over the past three million years, i.e., during the Quarternary Period. As this has been, and continues to be, an ongoing erosional/depositional process, new acid-generating mineralized material is continually being added, as the in-situ material oxidizes and slowly dissolves.

3.3 RED RIVER WATER QUALITY

3.3.1 INTRODUCTION

1. The reasons the available data does not support the conclusion that water quality in Red River has worsened between the 1960s and the 1990s due to mining activities are as follows:
   - **Climatic Trends:** The 1960s data was collected during a much drier period than the 1980s and 1990s information and cannot, therefore, be compared to the later data as constituent loadings to the river naturally increase during wetter periods.
   - **Reductions in Migration of Constituents:** Certain aspects of the Molycorp mining activities have resulted in reductions in the migration of constituents to the Red River.

   Each of these reasons are discussed in more detail below.

3.3.2 CLIMATIC TRENDS

1. As shown in Figures 4 and 5, both the precipitation and the flow in Red River have increased significantly from the 1960s through the 1990s. These graphs show the five-year moving average precipitation and runoff and therefore reflect the average annual accumulation over the previous five years. This approach is commonly used to establish trends in data; it makes these trends more visible by averaging out the extreme wet and dry years.

2. Figure 5 shows that average Red River flows have increased from approximately 30 cubic feet per second (cfs) in the 1960s and 1970s to 50 cfs in the 1980s and 1990s. As a result, the catchments adjacent to the river would have been a lot wetter in the 1980s and 1990s, thereby increasing the flushing of constituents into the river. Wetter conditions result in:
   - Higher rates of infiltration through the unsaturated soils and fractured bedrock containing weathered, mineralized material above the ground water table.
   - Higher ground water levels contacting more weathered mineralized material.
   - Increased ground water flow resulting in increased rates of constituent migration into the Red River.

3.3.3 REDUCTIONS IN MIGRATION OF CONSTITUENTS

1. Several of the mining and related activities result in reductions of constituent loads to the Red River. These include:
   - The dewatered underground mine workings which intercept a large proportion of the ground water flow towards the Red River as shown in Figure 3 (see discussion in Section 3.2.1).
   - The stormwater control systems prevent surface runoff contribution of both dissolved constituents and sediment into the Red River.
   - The diversions from Capulin Canyon to Goathill Creek reduce the constituent load in seepage for the upper portion of Capulin Canyon.
   - The subsidence area, intentionally created in the Goathill drainage, captures the surface runoff and seepage from the upper portion of Goathill Creek and conveys it to the underground workings.

3.4 SOURCE OF CONSTITUENTS IN RED RIVER

1. The available data do not allow for determination of whether constituent loadings in Red River are derived from overburden piles, natural scar areas, or from the alluvial deposits within the tributary and Red River channels. The reasons for this are that there are a large number of processes that determine whether constituents from the overburden piles actually migrate to Red River, most of which have not been characterized. These processes include : (1) the relative loadings of overburden piles and natural scar areas which determine what the potential proportion of source constituents are due to the overburden piles; (2) the migration pathways through the unsaturated zone and then through ground water; (3) the extent of geochemical changes that occur in seepage as it migrates through alluvium and fractured bedrock; (4) the extent to which the natural alluvial material, which contains mineralized material, impacts Red River water quality; and finally (5) the extent to which the Red River water itself chemically controls the constituent levels in the water.

2. The relative TDS loading from the bottom of an overburden pile, which is not indicative of what may reach the Red River, is different and possibly much lower than from natural scars because:
   - The overburden piles contain a very large proportion of gravel and boulder-sized material which typically only provide a fraction of the constituent load compared to finer-grained materials such as sands and silts, which are the predominant composition of the scar areas.

- The scar areas are more uniformly flushed by rainfall and infiltration as they contain more uniform material. Therefore, there is an increased potential to leach out more of the constituents than in the overburden piles. Infiltration through the overburden piles tends to be varied and most of the infiltration water typically only contacts a portion of the material, thereby reducing the mass of constituents that can be leached.

3. The laboratory shake tests conducted by SRK (SRK, 1995) are not representative of the relative loadings of overburden piles and scar areas. Plaintiffs' expert Dr. Williams has concurred with the conclusion that shake tests are not representative (Williams Deposition, 1997, page 130). Shake tests are not representative because:
   - Shake tests involve an agitated mixing of the material and water. This typically results in dissolved loads much higher than in nature where precipitation trickles over or through material.
   - Infiltration through overburden piles, while diffuse, varies significantly from one area to the next and may not reach all portions of the overburden material. This infiltration pattern further reduces loads for overburden piles and cannot be taken into account in shake tests.

4. While it is known that natural scars contribute significant loadings to Red River, without knowing the relative loading of overburden versus a scar it is not possible to calculate whether loadings to Red River have changed due to mining. While mining activities have increased the area of overburden that could potentially drain to Red River, they have also captured a substantial portion of the seepage emanating from both scar and overburden areas. In some areas overburden has been placed directly on scar material and the effect of this on the residual load from this combined area is also unknown.

5. As discussed in Section 3.1, potential flow pathways from the overburden piles are extremely large in number, variable in direction and generally difficult to impossible to define.

6. As discussed in Section 3.2 above, there are a range of geochemical changes that occur as the loading emanating from the bottom of an overburden pile migrates downward and laterally. These changes can potentially increase constituent concentration if the host material is acid-generating, or reduce concentrations if the host material has attenuative capacity.

4.0 COMMENTS ON PLAINTIFF'S EXPERT REPORTS

4.1 DIRECT HYDRAULIC CONNECTION

1. Plaintiffs' experts claim that there is direct hydraulic connection between the overburden piles and Red River, and that there are sufficiently well-understood preferential flow pathways for ground water movement from the overburden piles to Red River (Kelsey, 1997, *Opinion 1*; Mink, 1997, *Opinion 1*; and Williams, 1997, *Opinions 1 and 2*). However, no evidence is presented to support these opinions, and as outlined in Section 3.0, the evidence that is available supports the contrary conclusion, i.e., that there are no discernible, confined and discrete conveyances from the mine's overburden piles to Red River.

2. Plaintiffs' experts claim that because the Red River adjacent to the mine area is gaining, i.e., it receives recharge from the adjacent land areas, and because the overburden piles are located on that adjacent land area on permeable alluvium and bedrock, a direct hydraulic connection exists (Kelsey, Page 4; Mink, Page 7). The hypothesis stated simply indicates that ground <u>water</u> can migrate from higher ground to a lower area. It does not take into account the extremely complex geology (which has a very strong influence on the direction of migration of ground water); seepage collection; underground mine dewatering; or the complex chemical reactions that occur between ground water and the alluvium and fractured bedrock, which strongly influences to what extent <u>constituents</u> in the water migrate or are attenuated.

3. Plaintiffs' general claim that the Red River is gaining is an oversimplification and specific data I was able to locate shows that the opposite may be true for large portions of the Red River reach along the mine area. The 1988 evaluation completed by USGS (USGS, 1988) indicates that the reach between the mill down to 300 feet above the mouth of Columbine Creek, loses 1 cfs (approximately 450 gpm) of flow. Furthermore, the ground water level data presented in SPRI's report (SPRI, 1995, Figure 5) and collected by the mine in the ground water wells MMW-10A, B and C and -11 (Molycorp, 1997) shows there is a gradient away from the river into the bedrock under the Sugar Shack overburden pile, which is consistent with the Red River being a losing stream in this area.

4. The significance of the above losing river segment is that it occurs in the area where some of the largest overburden piles, i.e. Sugar Shack South, Middle and Sulphur Gulch, are located

relatively close to Red River. In areas where the river is recharging ground water under these piles, there would obviously be no potential for any constituent loading to the river from these overburden pile areas. To the extent these loses persist over time, they reduce the potential loads calculated for this reach shown in Figure 6 and discussed in Section 3.3, as these calculated loads assume this is a gaining reach.

5. Plaintiffs' expert makes the general assertions that because the overburden piles are in the recharge areas, and the seepage zones are in discharge areas, and because the primary aquifer systems within the mine area are sufficiently well understood, this represents a basis for finding a direct hydraulic connection between the overburden piles and the Red River (Kelsey, 1997, page 4). This general conclusion does not take into account all the site specific facts, such as those listed below:

    - Plaintiffs' experts do not appear to take into account the important fact that before mining, the bedrock and the alluvium, including the alluvium in the tributary channels as well as Red River itself, all contained naturally mineralized material that had resulted in widespread ground and surface water impacts. SPRI accurately characterized this condition by stating: *"Naturally acidic waters have been in transit through the same system, excluding seepage barriers, for thousands of years as is evident from limonite-cemented alluvial and mudflow deposits."* (SPRI, 1995, page 6).
    - The seepage zones referred to in the references cited (SRK, 1995, pages 11-12, and 21; SPRI, 1995, page 5; NMED, 1996, pages 16 and 33), include Capulin Canyon, Highway 38, Cabin and Portal. With the exception of Portal, these seepage zones are not located in close proximity to the overburden piles, or in downgradient areas, and it cannot therefore be concluded they are discharge areas for infiltration through overburden piles (see Figure 1.6, page 12, SRK, 1995).
        - The Capulin seepage zone is located approximately 5,000 feet (1 mile) downgradient from the closest mapped natural scar area and over 8,000 feet (1.5 miles) downgradient from the Capulin overburden pile. In any event, seepage from the Capulin overburden pile is intercepted and conveyed to the underground mine workings. The Capulin seepage zone is located in a fan delta deposit of alluvium which contains naturally occurring acid-generating mineralization. Thus, the fan delta deposit itself is the most likely source of constituents in the Capulin seepage zone.

- The Highway 38 seepage zone is located approximately 2,500 feet downgradient from a portion of the Sugar Shack West overburden pile.
- The Cabin seepage zone is located downgradient from a small natural drainage area. This zone is over 1,500 feet away from a large natural scar area and the Sugar Shack South overburden pile located in an adjacent drainage to the northeast.
- The Portal seepage zone is located 500 to 1,000 feet downgradient from the large natural scar area and Sugar Shack South overburden pile.
- The Sulphur Gulch seepage zone is located close to the toe of the Sulphur Gulch overburden pile, and less than 1,000 feet downgradient from a large natural scar area. While this zone is close to an overburden pile it has among the lowest constituent loadings of all the seepage zones on Red River (SRK, 1995, Table 1.4). For example, TDS and sulfate were measured to be 540 mg/l and 260 mg/l respectively. By comparison, values for water samples in Hansen Creek are much higher (SRK, 1995, Table 3.1). The measured TDS and sulfate concentrations are 2,620 mg/L and 1,544 mg/L respectively. This further demonstrates that the available data is not amenable to identifying specific sources to Red River.

• Mr. Kelsey's reference to overburden piles being placed over natural tributary channels which drain to Red River (SPRI, 1995, page B-3) is also not necessarily an indication that infiltration of water through the overburden piles would increase constituent loads to the river. All the tributaries that drain the mine area, i.e., Capulin Canyon and Goathill, Sulphur, Blind, and Spring Gulches, contain either naturally mineralized scars, or alluvial fan deposits derived from the erosion of scars, or both. The effect of this natural mineralization on the seepage water quality has not been characterized to the extent it is possible to indicate whether the overburden piles have had any impact on Red River water quality.

6. As discussed in Section 3.2, the complex nature of the seepage system, the chemical interaction between seepage, ground water and the alluvium or fractured bedrock, and the unpredictability of any connection between seepage from the overburden piles and the Red River, are highlighted by the fact that the major contributions of TDS, sulfate and metals to the Red River does not occur in the Red River reach (from the mill site to 300 feet above the mouth of Columbian Creek, Stations 7 to 10 in Figure 6) where over 50 percent (approximately 180 million tons) of the overburden piles are located along the Red River, or necessarily in areas where the scar areas are closest to the Red River (Table 1.1 and

Figure 1.2, SRK, 1995). The highest loads occur in Cabin seepage zone and in the Town of Red River, with the next higher in the Hansen Creek and Eagle Rock campground areas. Only one of these areas is within the mine site (Figure 6).

7. As further support for direct hydraulic connection, Dr. Mink (Mink, 1997, page 7) indicates that *"data show that water from mine wastes contains significantly greater concentrations of sulfate and metals (aluminum, iron, manganese, zinc, copper, cadmium) than water from scar areas."* However, no facts are provided to substantiate this statement. While water samples collected below the Capulin overburden pile (WS-CAP1 and WS-GC1) have high concentrations, it is not evident whether these are due to the upgradient overburden or the underlying scars (Figure 1.5, SRK, 1995). By contrast, the water samples collected on top of the Sugar Shack South overburden pile (WS-SS1 and WS-SS2) have very low concentrations, lower than the concentrations below the natural scars in the Hansen Creek area.

8. Dr. Williams uses water quality data and the fact that the same constituents occur in the overburden piles as in Red River, to conclude that there is direct hydraulic connection between the overburden piles and Red River (Williams 1997, page 7). This approach is too simplistic as it does not make adjustments for constituents that are added from naturally occurring mineralized material in the alluvium, in the creek and river beds, and in the fractured bedrock, nor does it account for the attenuation of the overburden pile derived constituents in these same materials. Dr. Williams furthermore also fails to point out (Williams, 1997, page 8) that most of the water samples collected downgradient from overburden piles could also be impacted by natural scar material located under and adjacent to these overburden piles.

9. Dr. Williams makes the statement that *"seepage flows laterally downhill along low hydraulic conductivity barriers at the base of the waste rock"* (Williams, 1997, page 4). This is not substantiated by any of the data. Dr. Williams provides no evidence of any such barriers, in fact the available information, which indicates that bedrock is highly fractured and faulted, suggest that such barriers are not present. It is not clear how an estimate of the relative amount of ground water flow intercepted by the underground mine working cone of depression can be attempted when Dr. Williams has made no attempt to estimate the size of the cone of depression.

10. Dr. Williams' claim (Williams, 1997, pages 8 and 9) that the timing of the appearance of the white precipitate in Red River verifies a hydraulic connection, has no factual basis. No reliable scientific data is provided to support the sudden appearance of new seeps and springs since mining started. For one, the premining data collection efforts were much less intense than those of the late 80s and 90s. To my knowledge, there is no documented systematic seep survey that characterizes seeps over time on a scientific basis. I have also not seen any evaluations of the appearance and disappearance of seeps that takes into account the effect of natural seep fluctuations. Any references therefore to finding new seeps and springs is likely due to a large number of nonmining related factors including more intensive observation of the river banks, different observational and seep characterization skills by the various parties involved, varying precipitation conditions causing increases or decreases in seepage flow rates prior to the observations, and varying snowmelt conditions.

11. Dr. Mink furthermore claims that seepage from Capulin Canyon overburden pile potentially contributes sulfate and metals to Red River (Mink, 1997, page 8). Even if a portion of the subsurface seepage from the Capulin Canyon overburden pile bypasses the seepage collection and diversion system, there is no evidence to indicate these constituents in this seepage reach Red River. There is a large expanse of alluvium and fractured bedrock, over 1-1/2 miles long below the overburden piles that not only contains naturally occurring mineralized material derived from scar erosion, but also contains attenuation capacity which would reduce naturally the seepage and reduce the metal concentrations. It is therefore, equally likely that the quality of seepage that does get into Red River is largely dependent on the chemical properties of these natural materials. In addition, a fault traverses along the upper portion of Capulin Canyon. It likely extends to great depth, also providing a deep migration pathway into the bedrock below the Red River.

4.2 PREFERENTIAL FLOW PATHWAYS

1. Mr. Kelsey's claims (Kelsey, 1997, page 7) that both perched ground water conditions and the presence of fractures and faults provide preferential pathways are unsubstantiated.

2. The perching conditions referenced by Mr. Kelsey (SPRI, page 6) are stated to be speculation by SPRI themselves: *"Perched water **can** form near the base of the waste rock dumps. Perched water **can** form in zones of fractured bedrock above the main water table and above clay intervals in the valley fill. Bedrock seeps, such as the seeps at Cabin Springs, near the river, **may** be from a perched bedrock zone."* Furthermore SPRI provides no evidence or any further discussion to confirm this speculation. Finally, in an alluvium-fractured bedrock system such as the one at the mine site, widespread perching generally does not occur. Because it consists of permeable alluvium overlying permeable fractured bedrock, the ground water it contains represents a single aquifer system which fills from the bottom up. As I indicated, isolated perched conditions can occur; however, their presence would have to be identified by data, not simply by speculation.

3. The faulting and fracturing referred to by Mr. Kelsey (SPRI, 1995, Figure 3, Pages 5 and B1; Plate 2: Geologic Map of the Questa Mine Area, and Plate 1: Geologic Map and Cross Sections of the Questa Mining District) does not support his opinion on preferred pathways.
   - Figure 3 (SPRI, 1995) simply shows a geologist's conceptual definition of some of the flat lying, east-west trending faults in the area. These lines do not connote flow pathways, but merely the location of faults that are typically irregular bands of sheared and fractured rock, and that can vary in thickness up to ten or hundreds of feet. They can also include areas where the fault zone is very thin and impermeable. Furthermore, between the indicated faults there are other known and unknown faults, and between the fault zones there is fractured bedrock. All of the above fractures can convey water in a diffuse but variable pattern.
   - The other SPRI references simply contain geologic descriptions of fault systems and do not indicate preferred pathways.

4.3 GROUND WATER MIGRATION CAPTURE BY THE UNDERGROUND MINE

1. Plaintiffs' witnesses also claim that the ground water cone of depression created by dewatering the underground mine does not capture a significant portion of the shallow ground water within the mine area (Mink, 1997, Opinion 2; Kelsey, 1997, page 4) due to perching of ground water and low permeability bedrock in the vicinity of the underground mine. The available data indicates the contrary, i.e.:
   - As previously discussed, the referenced SPRI statements of perching water under waste dumps and along the edge of the river

(SPRI, 1995, page 6) are speculative and no supporting evidence is provided. My experience at several mines with similar geologic conditions is that widespread perching typically does not occur.

- The referenced SPRI statements regarding potential perching in the alluvium between the Sugar Shack south overburden pile and Red River in the vicinity of Monitoring Wells MMW-10A, B and C have been misinterpreted (SPRI, 1995, page 12).
  - SPRI indicates its preferred explanation for the results of the pump test conducted in the MMW-10A well in this area is that the water was <u>not</u> perched (SPRI, 1995, page 13). I concur with SPRI's conclusion that there is merely a lower permeability zone in the area between the two well screens in MMW-10A and -C. This is also consistent with my ground water flow analysis outlined in Chapter 3.0 which accounts for such local heterogeneities.
  - It is generally not possible to have perched water develop in alluvial deposits adjacent to rivers as these deposits are usually totally saturated up to at least the water level in the river. The suspected perched zone was indicated to be below the river's water level (SPRI, 1995, page 12) which is implausible.
  - There is reference to another potentially localized perched ground water zone in the MMW-7 well area in the SPRI report (SPRI, 1995, page 11, and Figure 8) which is interpreted by SPRI not to have any effect on the amount of water captured by the underground mine workings. As shown in their Figure 8 (SPRI, 1995) and Figure 3 attached to this report, ground water under this potentially perched area can migrate into the underground workings if the water in MMW-7 is perched.

2. The other reasons the plaintiff's experts use to imply that seepage capture by the underground mine is not significant are unconvincing. In some cases, closer examination of the data referenced in the experts' citations actually substantiates the opposite, i.e., that capture is significant. Mr. Kelsey refers (Kelsey, 1997, page 6) to the SPRI reports (SPRI, 1995, page B-7) ... incorrect conclusion, and ignores basic data in the SPRI document that shows significant capture is being achieved.

   - Because the net accretion to Red River in the mine area was measured to be the same in 1988 as it was in 1965, in spite of mine dewatering from the new underground mine that took place from the mid 1970s onwards, SPRI concluded mine dewatering did not influence or intercept any accretion to the river (SPRI, 1995, page B-7). This conclusion ignores a very well established hydrologic principal, which is that net accretion to river segments continually changes with time as it depends predominantly on both the amount and the pattern of precipitation and temperature over the previous weeks, months and even years. Therefore, using differences in the estimated accretion in two different periods to calculate how much water is being abstracted by a mine is meaningless and could result in a wide range of values.

- Reference to Figure 8 in the same report (SPRI, 1995) clearly shows that the underground mine had a significant capture zone extending from the east near Sulphur Gulch to the west, close to Goathill Gulch, and to the south close to Red River. This significant capture zone is consistent with my own assessment of the capture achieved by the underground mine (see Figure 3 of this report).
- Both SPRI (SPRI, 1995, page B-7) and by reference Mr. Kelsey incorrectly indicate that *"most of the ground water recharge to the river may have come from the upper part of the ground water system. In other words, the deep mine was not directly in the recharge zone."* Even though there may be different hydrologic units such as alluvium, shallow fractured bedrock, and deeper bedrock, there is generally only <u>one</u> ground water system at the site. With the exception of possible localized perched conditions at MMW-7 and potentially other isolated areas, the ground water in the mine site area is continuous. Therefore, creating a cone of depression in an area will capture all ground water flow that occurs within the capture zone. Ground water cannot, as plaintiffs' expert implies, migrate over the top of a several-hundred-foot-deep ground water depression. The effect of dewatering the mine has been measured as far away as approximately 5,000 feet at MMW-13.

3. Dr. Williams claims that because water levels in wells MMW-10A, B and C, and MMW-11 had not responded to mine dewatering, this indicated the capture zone of the mine was limited. Review of all the available information however (Molycorp, 1997) indicates there have been significant responses in the alluvium at MMW-10A, 9.22 feet drawdown, and MMW-10C, 8.66 feet and in shallow bedrock at MWW-10B, 9.18 feet, and MMW-11, 8.34 feet over the period May 1995 through February 1997. The lack of response in MMW-7 can be attributed to the anisotropic nature of fractured bedrock systems, i.e., directional permeability and storativity variations which will affect the time response of drawdown cone development on locally perched water conditions.

4.4 RED RIVER WATER QUALITY

1. Both Mr. Kelsey (Kelsey, 1997, Opinion 3) and Dr. Williams (Williams, 1997, Opinions 3 and 4) claim that the mine has worsened the water quality in the Red River. Mr. Kelsey's two main reasons are: (1) his theory on hydraulic connection, which as discussed in Section 3.1 is

not substantiated by the scientific data, and (2) the water quality data from the Red River. Dr. Williams attributes her opinion to the apparent increases in constituent loadings measured in Red River.

2. Dr. Williams claims that *"sulfate and metal loadings in the reach of the Red River adjacent to Molycorp Mine is more attributable to mining activities and emplacement of waste rock piles than to natural hydrothermal scars"* (Williams, 1997, Opinion 3, Page 5). The Red River water quality data relied on does not demonstrate that constituent loads to the Red River increased from 1966 to 1992 due to mining activities. As discussed in Section 3, there are other factors that cause changes to constituent loads to the Red River.

3. Mr. Kelsey has claimed that the Moly Tunnel *"caused the subsequent emergence of Portal Spring"* (Kelsey, 1997, Page 9). This statement is unsubstantiated, and the limited data that is available suggests that the "Moly Tunnel" does not likely represent a measurable source of seepage to Red River.

4. While the Moly Tunnel drained, the limited flow was reported to have been collected and reused in the mill (Dave Schoemaker Deposition, 1996). Flow in the tunnel is reported to have been derived from ground water inflow to the historic underground mine and precipitation recharge through the open pit, both of which are located at the upper end of the Tunnel. Once the new underground mine went into production (i.e., early 1980s), water no longer flowed out of the Tunnel, but was collected and drained down into the mine via a winze (i.e., a vertical shaft internal to the mine workings). Thus the volume of water Mr. Kelsey assumed would be accumulating behind the plug actually flowed down into and is collected in the underground workings. The Tunnel mouth was plugged in 1992 to avoid surface discharges in the event the winze became plugged (David Shoemaker Deposition, 1996).

5. Recent inspections of the plug by Molycorp staff (Molycorp, 1997) indicate that there has been only a small (approximately two feet) of head behind the plug. The amount of standing water is relatively small and is not likely to cause any measurable increase of seepage to Red River. The effect of this small amount of water is that of a small surface pool of water located approximately 200 feet from the Red River.

Ian P.G. Hutchison

Dated: April 23, 1997

TABLE 1

CALCULATION OF TOTAL AVERAGE BASEFLOW AND RUNOFF FROM MINE AREA FOR PERIOD 1980 TO 1993

• Average Streamflow for Period 1943-1955 (Gauge near Questa):		48.6 cfs
• Average Streamflow for Period 1980-1993 (Gauge near Questa):		50.8 cfs
• Average Streamflows for Common Period 1943-1964 (22 years)		
- Gauge near Red River (19.1 square miles):		17.04 cfs
- Gauge near Questa (113.0 square miles):		44.70 cfs
Increase:		27.66 cfs over 93.9 square miles
	=	0.295 cfs/square mile
• Average Streamflow for Common Period 1963-1973 (11 years)		
- Gauge below Zwergle Dam (25.7 square miles):		17.27 cfs
- Gauge near Questa (113.0 square miles):		32.10 cfs
Increase:		14.83 cfs over 87.3 square miles
	=	0.170 cfs/square mile

Average Increase in Streamflow = (22 x 0.295 + 11 x 0.170)/33 = 0.253 cfs/square mile

Amount of Base Flow (Recharge) Calculated by SPRI = 11.04/87.3 = 0.126 cfs/square mile

Amount of Surface Runoff Calculated by Differencing

= 0.253 - 0.126
= 0.127 cfs/square mile

For 1.81 square miles (1,160 acres = 575 + 585)

= 0.230 cfs
= 103 gpm

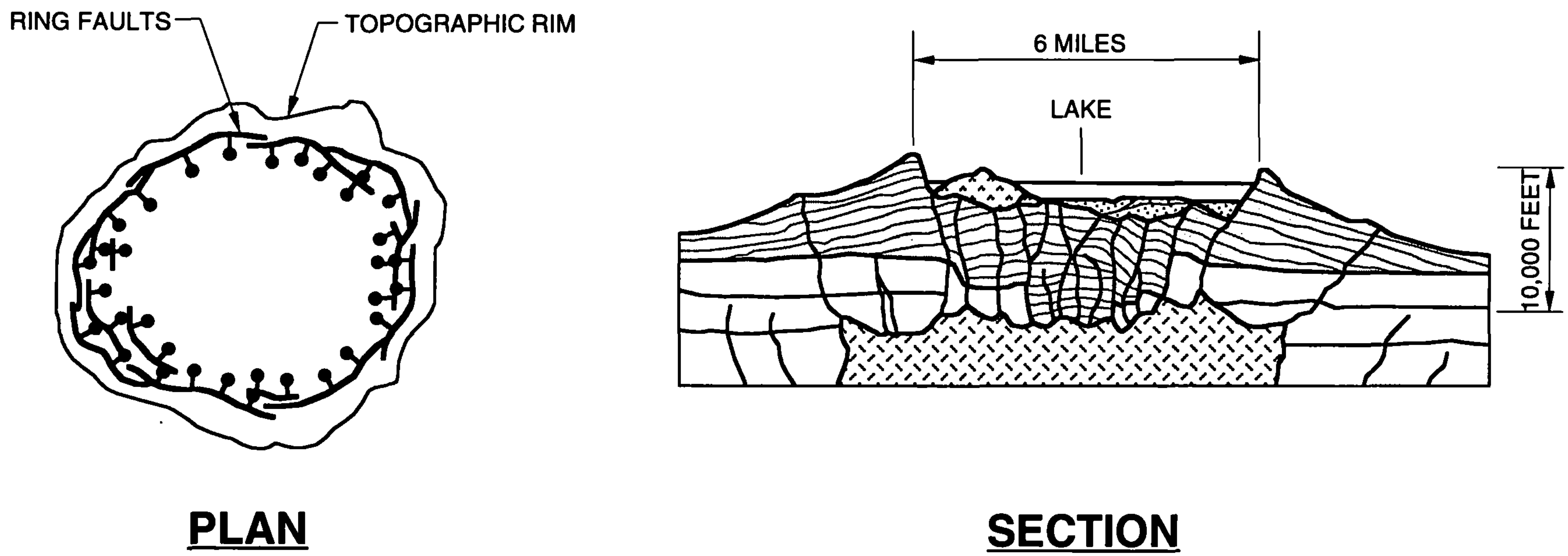
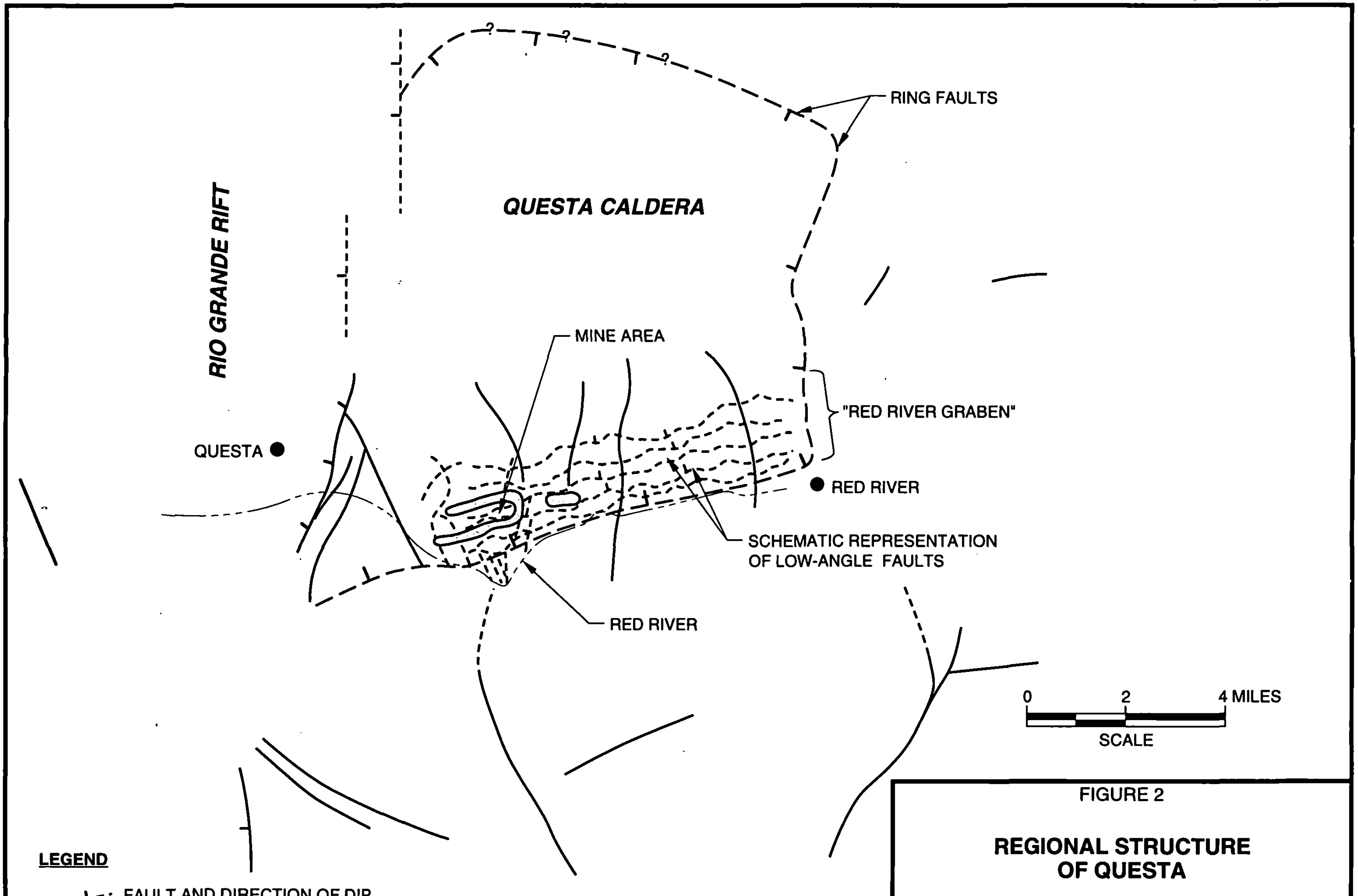


FIGURE 1

CONCEPTUAL PRESENTATION OF FAULTING IN A TYPICAL CALDERA (BASED ON CRATER LAKE, OREGON TWISS AND MOORES, 1992)

TRC ENVIRONMENTAL SOLUTIONS, INC.



ADAPTED FROM:

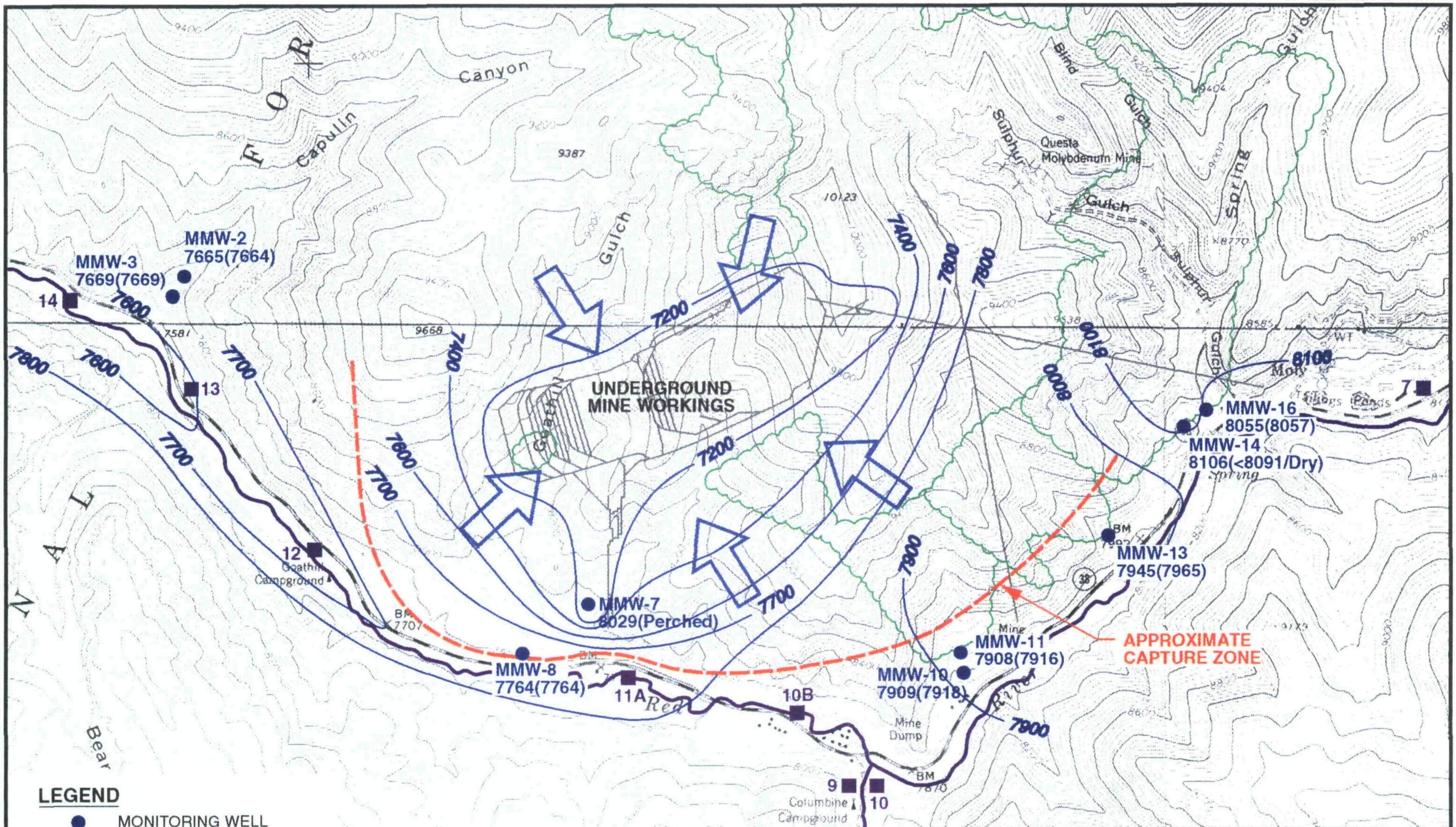
1. DANE AND BACHMAN, 1965, GEOLOGIC MAP OF NEW MEXICO
2. McKINLEY, 1957, GEOLOGY OF QUESTA QUAD
3. MEYER AND LEONARDSON, 1990.

FIGURE 2

REGIONAL STRUCTURE OF QUESTA

TRC ENVIRONMENTAL SOLUTIONS, INC.

97-122EW-02 REV.4/21/97



LEGEND

- ● MONITORING WELL
- 7908 FEBRUARY 1997 ELEVATION
- (7916) JANUARY 1996 ELEVATION
- ■ RED RIVER SAMPLE LOCATION
- GROUND WATER FLOW DIRECTION
- OVERBURDEN DISPOSAL PILES (SRK, 1995)

0 2000 4000 FEET

SCALE

REFERENCE: U.S.G.S. TOPOGRAPHIC MAPS OF QUESTA AND RED RIVER, NEW MEXICO DATED 1963.

FIGURE 3

GROUND WATER CONE OF DEPRESSION CREATED BY DEWATERING OF THE UNDERGROUND MINE

TRC ENVIRONMENTAL SOLUTIONS, INC.

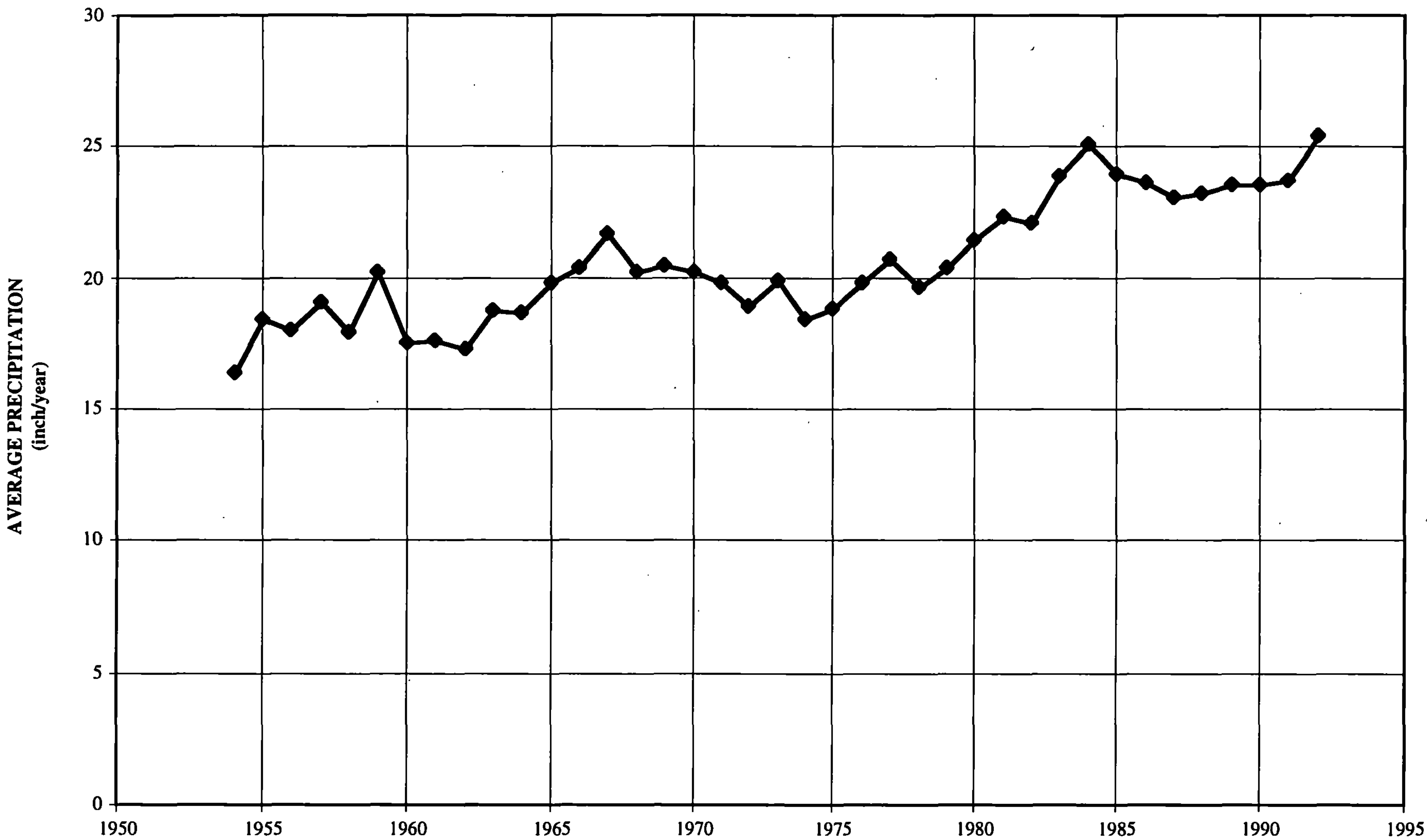


FIGURE 4

**FIVE YEAR
MOVING AVERAGE PRECIPITATION
AT RED RIVER**

TRC ENVIRONMENTAL SOLUTIONS, INC.

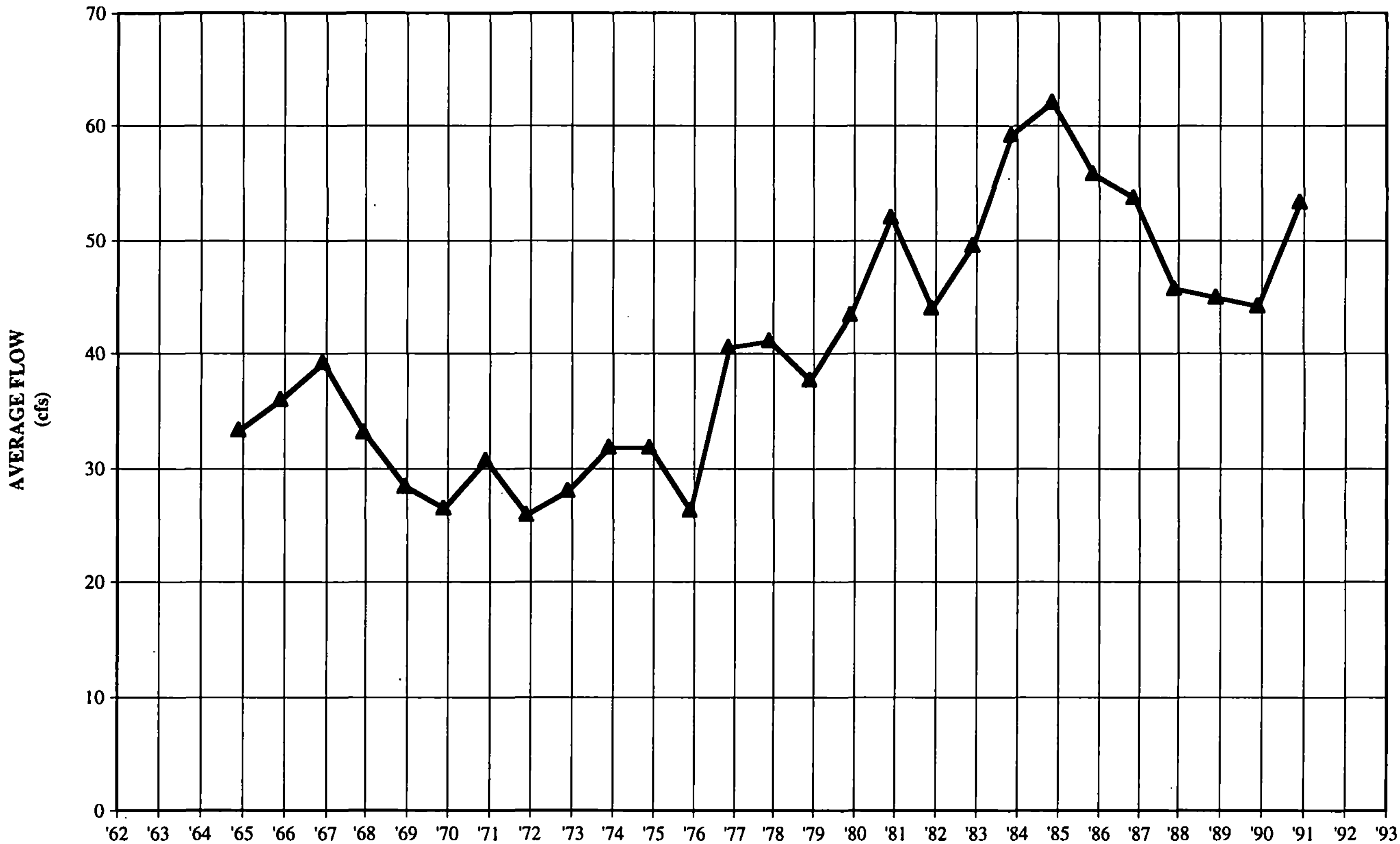
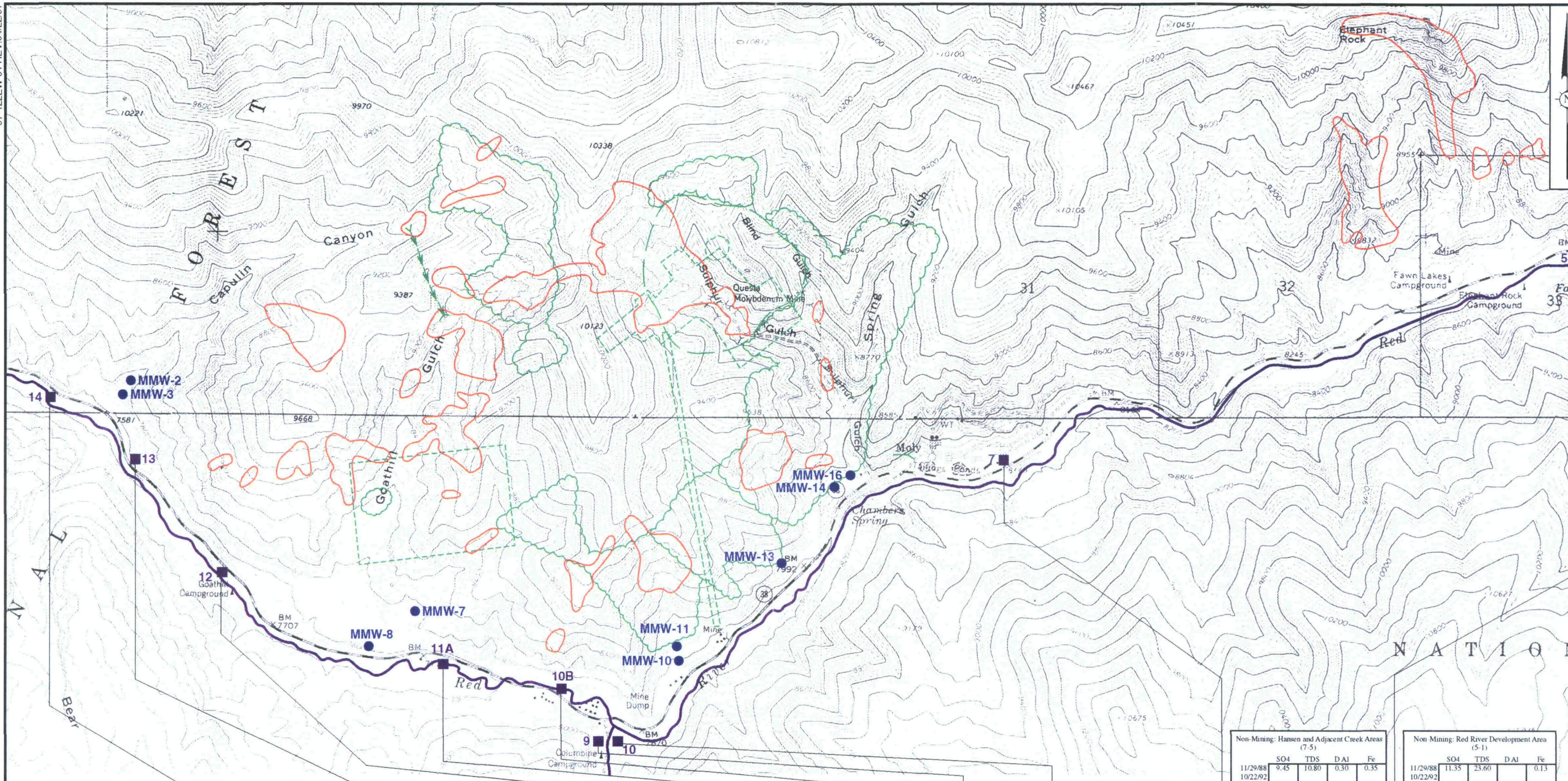


FIGURE 5

**FIVE YEAR MOVING AVERAGE
RED RIVER FLOW NEAR QUESTA**

TRC ENVIRONMENTAL SOLUTIONS, INC.

97-122EW-01 REV 04/22/97



Non-Mining: Catchment Areas Downgradient from the Mine Site (17-14)

	SO4	TDS	D Al	Fe
11/29/88	9.38	29.82	0.20	0.42
10/22/92	9.60	30.54	0.21	-0.06
2/16/93				
11/10/93	-2.46	0.69	0.29	1.29
2/11/94				
10/13/94	37.44	23.73	0.00	0.10
2/14/95	10.69	37.23	-0.01	0.06
11/9/95	4.21	-37.22	0.02	-1.74
2/26/96	5.51			
Average	10.63	14.13	0.12	0.01
Ranking:	6	6	3	6

Mining: Capulin Creek Area (14-13)

	SO4	TDS	D Al	Fe
11/29/88	-2.79	-1.50	0.33	0.09
10/22/92	13.40	33.72	0.01	0.05
2/16/93	10.34	10.96	0.01	0.11
11/10/93	6.42	9.60	0.74	4.16
2/11/94	2.46	5.07	0.01	0.49
10/13/94	-2.24	5.53	0.01	0.07
2/14/95	3.29	2.03	0.00	-0.56
11/9/95	-0.57	61.18	-0.02	1.69
2/26/96	11.87			
Average	4.69	15.82	0.14	0.76
Ranking:	8	4	2	1

Mining: Remainder of Catchment Area Adjacent to and West of Goathill Creek (13-12)

	SO4	TDS	D Al	Fe
11/29/88	11.71	8.11	0.19	-0.10
10/22/92	-4.59	-14.64	-0.03	0.01
2/16/93	-2.78	0.38	0.00	0.01
11/10/93	0.18	-21.46	0.14	-0.47
2/11/94	5.19	8.56	0.00	-0.62
10/13/94	6.21	0.46	0.00	0.02
2/14/95	2.51	1.53	0.00	0.62
11/9/95	6.09	-15.79	0.01	0.08
2/26/96	0.19			
Average	2.75	-4.11	0.04	-0.06
Ranking:	9	9	6	8

Mining: Goathill Creek Area (12-11A)

	SO4	TDS	D Al	Fe
11/29/88				
10/22/92				
2/16/93				
11/10/93	17.07	-0.40	-0.11	0.99
2/11/94				
10/13/94	19.27	22.53	0.01	-0.07
2/14/95	18.17	11.07	-0.05	0.46
11/9/95	13.35	25.71	0.01	-2.78
2/26/96	8.98			
Average	15.37	14.73	-0.04	-0.35
Ranking:	2	5	8	9

Mining: Remainder of Catchment Area Adjacent to and East of Goathill Creek (11A-10B)

	SO4	TDS	D Al	Fe
11/29/88				
10/22/92				
2/16/93				
11/10/93	18.75	33.57	-0.13	0.10
2/11/94				
10/13/94	11.72	-4.73	0.00	0.02
2/14/95	2.95	-5.57	-0.10	0.08
11/9/95	5.86	1.65	0.02	2.31
2/26/96	-1.11			
Average	7.64	6.23	-0.05	0.63
Ranking:	7	8	9	2

Mining: Catchment Area opposite Columbia Creek (10B-10-9)

	SO4	TDS	D Al	Fe
11/29/88	-35.95	-84.50	-0.72	-0.22
10/22/92	13.49	20.15	0.07	-0.04
2/16/93	15.92	36.07	0.06	-0.14
11/10/93	6.34	21.72	0.13	-0.03
2/11/94	12.97	22.37	0.05	0.28
10/13/94	34.24	30.65	0.08	0.00
2/14/95	17.10	14.18	0.08	-0.01
11/9/95	12.70	33.66	-0.03	0.35
2/26/96	29.00	0.00	0.00	0.00
Average	11.76	10.48	-0.03	0.02
Ranking:	4	7	7	5

Mining: Mill, Portal Spring, and the Spring Gulch, Sulfer Gulch, Middle and Sugar Shack South Overburden Disposal Pile Area (10-7)

	SO4	TDS	D Al	Fe
11/29/88	13.07	21.98	0.10	-0.30
10/22/92	17.58	14.19	-0.09	-0.02
2/16/93	10.46	17.25	0.01	0.10
11/10/93	4.13	20.94	0.46	-0.09
2/11/94	16.41	21.39	0.01	0.20
10/13/94	12.33	19.15	0.10	-0.02
2/14/95	3.59	8.38	0.01	-0.06
11/9/95	13.18	13.67	0.00	0.10
2/26/96	6.61			
Average	10.82	17.12	0.07	-0.01
Ranking:	5	3	5	7

Non-Mining: Hansen and Adjacent Creek Areas (7-5)

	SO4	TDS	D Al	Fe
11/29/88	9.45	10.80	0.30	0.35
10/22/92				
2/16/93				
11/10/93	8.61	26.01	0.37	-0.05
2/11/94				
10/13/94	20.05	22.69	0.02	0.12
2/14/95	14.99	18.26	0.01	-0.01
11/9/95	15.08	28.41	0.02	-0.05
2/26/96	16.09			
Average	14.04	21.23	0.14	0.07
Ranking:	3	2	1	4

Non-Mining: Red River Development Area (5-1)

	SO4	TDS	D Al	Fe
11/29/88	11.35	23.60		0.13
10/22/92				
2/16/93				
11/10/93	28.39	50.27	0.09	0.22
2/11/94	19.87	36.94	0.09	0.18
10/13/94	32.51	63.65	0.11	0.08
2/14/95	24.79	53.86	0.02	0.11
11/9/95	24.56	42.38	0.03	0.17
2/26/96	27.00			
Average	24.06	45.12	0.07	0.15
Ranking:	1	1	4	3

LEGEND

- MONITORING WELL
- RED RIVER SAMPLE LOCATION
- UNDERGROUND MINE WORKINGS AND OPEN PIT
- SCAR AREAS (SRK, 1995)
- OVERBURDEN DISPOSAL PILES (SRK, 1995)
- ADIT

0 2000 4000 FEET
SCALE

REFERENCE: U.S.G.S. TOPOGRAPHIC MAPS OF QUESTA AND RED RIVER, NEW MEXICO DATED 1963.

FIGURE 6

INCREMENTAL SURFACE WATER LOADINGS (GM/SEC)

TRC ENVIRONMENTAL SOLUTIONS, INC.

ATTACHMENT A

Ian P. G. Hutchison

EDUCATION

B.S., Civil Engineering, University of Capetown, South Africa, 1967.
Graduate Diploma, Hydraulic and Soils Engineering, University of the Witwatersrand, South Africa, 1974.
Ph.D., Hydrology, University of the Witwatersrand, South Africa, 1976.

EXPERIENCE DETAIL

1989-Present: Senior Vice President, TRC Environmental Solutions, Inc.

- Expert witness for the following:
  - Stringfellow Superfund site, California (surface water-VOCs and metals) (Deposition and Trial Testimony 1987 through 1993).
  - Rancho California Airport site, California (ground water - hydrocarbons) (Deposition).
  - John Wayne Airport site, California (ground water - VOCs) (Expert Report, 1990).
  - Testimony to the County Supervisors on the Briggs Mine EIR, Inyo County, California (mine waste management). (Hearing Testimony, 1995).
  - Iron Mountain Mine site, California (acid drainage, metals) (Expert Review, 1994).
  - Hope Brook Gold Mine in Newfoundland, Canada (mine waste management, surface water). (Expert Report, 1995)
  - Confidential gold mine site in the southwestern United States (mine waste management, surface and ground water) (Expert Report, 1996).
  - Stanford Research Park Industrial Complex in Palo Alto, California (ground and surface VOCs) Expert Report, 1993).
  - Hattiesburg Wood Treatment Site, Mississippi (soil and ground water-wood treatment chemicals) (In progress 1995 - 1996).
  - Meyer's Drum Reprocessing Facilities (soil and ground water PCBs, Bunker C, metals and COCs) (Expert Report and Deposition, 1996).

- Project Director or Principal-in-Charge for the following remediation projects:
  - Site characterization and remedial design for the historic Pacific Coast Pipeline Refinery/Superfund site in Fillmore, California involving heavy and light hydrocarbon fuels. Remediation included soil vapor extraction and ground water pump and treat.
  - Site characterization and remedial design for the Purity Oil Recycling Facility Superfund site which is impacted by hydrocarbons and volatile organics (VOCs). Remedial technologies included soil vapor extraction, capping and ground water pump and treat.
  - Site characterization, risk assessments and remedial planning for the large operating Unocal refinery at Wilmington. Constituents of concern included hydrocarbons and lead. Remedial technologies included capping, soil excavation and treatment, and in-situ ground water treatment.

- Site characterization and remedial design, and record of decision (ROD) changes, for the J.H. Baxter Superfund site in northern California. Constituents of concern include dense nonaqueous phase liquids (DNAPLs); i.e., creosote, polychlorinated phenols (PCP), and metals including arsenic, chromium and zinc. Remedial elements included soil excavation, ex-situ biotreatment, onsite disposal in a RCRA-equivalent cell, in-situ biotreatment, slurry wall and limited ground water extraction and treatment.
- Site characterization, remedial design, and ROD changes for the Cabot Carbon/Koppers Superfund site (Wood Treatment Plant) in Gainesville, Florida involving creosote, PCP and metals. Remedial technologies included capping and "passive" slurry wall systems.
- Site characterization and remedial design, and construction oversight for the Feather River Wood Treatment site in Oroville, California which involves creosote, PCP and metals. Remediation included soil excavation and disposal in onsite RCRA-equivalent cells.
- Site characterization and remediation planning at the Vega Alta industrial site in Puerto Rico (VOCs). Remediation included selective ground water pump and treat.
- Site characterization and remediation planning at the Boricua Wood Treatment site in Puerto Rico (arsenic). Remedial technologies included soil excavation, offsite disposal and capping.
- Site characterization, remedial planning and design, and remediation construction at a mercury mine and processing facility in California. Technologies employed included building decontamination and demolition, soil excavation stabilization and offsite disposal, and buried drum location and removal.
- Remedial design for closure of tailings piles at the Shafter Silver Mine in Texas. Closure included regrading and capping.
- Assessment of closure liability and costs including conceptual designs and cost estimates for acid mine drainage control and treatment systems at mines in Colorado, Idaho and Nevada as part of a corporate acquisition. Closure technologies included physical, chemical and wetlands (biological) treatment, regrading and capping.
- Corrective action planning and design for a RCRA wood treatment facility in Montgomery, Alabama (constituents of concern include PAHs, PCP, metals and dioxins). Corrective action technologies include a "passive" slurry wall.
- Site characterization and interim measures implementation and evaluation at the Charleston Superfund site (wood treatment plan) in South Carolina. The technology tested involved NAPL removal well systems.

• Project Director or Principal-in-Charge for the following mining projects:
  - Development of closure plans for the Cactus Gold Heap Leach Mine in Lancaster, California. Closure elements included regrading and backfilling of pond areas.
  - Development of closure plans for wastewater ponds and tailing impoundments, tailings impoundment corrective actions, and ground water impact characterization for the Molycorp Mountain Pass rare earth mine, California. Characterization involved demonstration of limited seepage migration from tailings impoundment, and remedial/ closure technologies included a seepage interception well system, innovative cost-effective silty material caps for landfills and tailings ponds, and improvements to the wastewater treatment system (neutralization and settling).
  - Development of closure plans for an acidic waste rock disposal pile at the Homestake Mine, California. Closure technologies included short-term leachate collection and return systems and long-term control by encapsulation of the waste rock in clay cells.

- Development of closure plans and designs, and permitting of wastewater transfers at the Royal Mountain King Gold Mine, California. Operation of mine site during closure period. Technologies employed included RO treatment and solar evaporation of wastewater, regrading, soil and composite covers for tailings ponds and earthfill dam construction to contain pit lake levels.
- Planning and conceptual design of wastewater disposal systems for the Sonora Gold Mine, California. Systems permitted included land application on waste rock piles and blending and discharge under the NPDES program.
- Seepage evaluations, design of seepage control systems and a spill control dam at the Cerro Verde Mine in Peru.
- Briggs Gold Mine heap leach environmental impact report (EIR), California.
- Soledad Canyon gravel mine and site infrastructure design for TMC.
- Permitting of three copper mines and associated processing plants (heap leaching, SX/copper sulfate and EW facilities) in COREMA Region II (Atacama Desert) in Chile.
- Remediation designs and closure plan development for four lead/zinc/copper mines in the Peruvian Andes. Technologies included regrading, capping, underground mine sealing and wetlands treatment systems.
- Characterization and remedial planning for the control of acid drainage from historic mines in the Moche, Llaucano, and Parcoy River Basins in northern Peru.

• Regulatory development activities, including:

  - Senior editor and author of a 650-page textbook on mine waste management.
  - Preparation of industry "strawman" mine waste regulations for California.
  - Senior editor and reviewer of the Arizona BADCT mine waste regulations.
  - Presentation of testimony on mine waste management to State Hearing Boards in California.

• Senior Review Consultant on the following projects:

  - OII municipal/industrial landfill Superfund site in California (cover design, leachate collection and treatment and ground water characterization and remediation).
  - Site characterization and remedial planning at the closed Casmalia RCRA hazardous waste landfill site, California. Remediation includes ground water trench collection systems and capping.
  - Design of the B-18 hazardous waste disposal cell at Kettleman Hills, California.
  - Expansion plans for the McFarland-Delano Municipal Landfill, California.
  - Lead-zinc mining district Superfund site RI/FS in Kansas and Missouri (Jasper County and the Baxter Springs-Treece Superfund sites).
  - Development of a strategic RCRA compliance plan and designs for FMC's lithium production facility in Bessemer, North Carolina.
  - Site characterization and remedial planning including technology impracticability evaluations for Bristol Meyers' Weck Industrial site in North Carolina.
  - Site characterization and remedial design for two drum recycling facilities in Oakland and Emeryville, California (VOCs, PCB, heavy hydrocarbons and metals).
  - San Fernando Valley Superfund Site (Glendale Operable Unit) 5,000 gpm ground water remediation project.
  - Reassessment of proposed remedial ground water pumping at an industrial site in Ontario, California. Alternative proposed utilized natural attenuation to limit ground water extraction and treatment.
  - Characterization of waste rock for the Mule Canyon Mine in Nevada.

1981-1989: Managing Principal and Division Head, Water Engineering, Steffen Robertson and Kirsten

- Responsible for the U.S. operations of the company, including several hundred projects involving waste management, water pollution control, land use and air quality permitting, and open pit mining.
- Direct technical management of solid waste disposal, hazardous waste and hydrologic work carried out by the company.
- Project principal in charge of the design and construction of mine tailings and waste rock disposal facilities in Alaska, Washington, California, Colorado, Utah, and Nevada.
- Expert witness on the Stringfellow Superfund Site.
- Technical oversight on investigations carried out on the Boulder Marshall Municipal Waste Landfill Superfund site in Colorado.
- Technical expert review work on ground and surface water and soil pollution problems on mining Superfund sites including California Gulch, Colorado, and Galena, Kansas. Development of a comprehensive approach for the development of ARARs.
- Presentation of specialist technical evidence for ground and surface water contamination problems at mine sites in California and New Mexico.
- Supervision of regional hydrologic and water balance studies for the Rio Grande River basin.
- Embankment dam design and construction in California and Washington (fill dam heights of up to 400 feet).
- Project management of the design of 100-acre waste water disposal ponds in California.
- Testimony on water quality and waste management issues at the State and Regional Water Quality Control Boards in California.

1976-1981: Hydraulics Department Head/Project Engineer, Acres International

- Hydrologic and hydraulic engineering aspects of all projects conducted in the United States, and maintaining a staff team to undertake the work.
- Hydroelectric projects in New York, Maine, Vermont, and Alaska, including the Susitna River project in Alaska.
- Industrial process plants and tailings disposal systems in Ohio and Colorado.
- Streamwater quality studies in New York.
- FEMA flood plain mapping studies.
- The hydrologic and hydraulic engineering associated with a wide range of irrigation, navigation, hydroelectric, and industrial projects throughout Canada, the United States, and South America.

- Irrigation schemes in the Dominican Republic and Bolivia.
- Design and construction of three ports on the Amazon River in Peru.
- Design and construction of hydroelectric generating stations in Newfoundland, Ontario, and Alberta, Canada.
- Large-scale river basin water balance studies in Alberta, Canada.
- Regional flood studies for the province of New Brunswick, Canada.

1970-1976: Research Officer, Hydrological Research Unit, University of the Witwatersrand, Johannesburg, South Africa

- The development and application of river basin catchment, ground water, lake and estuary computer models for the evaluation of salinity control measures of the St. Lucia Lake system.
- Provided input to the update of national design flood manuals.
- Numerous consulting assignments involving the development of surface water supplies and implementation of flood control measures for projects in South Africa, Botswana, and Lesotho.
- Conducted graduate courses in computer modeling of surface water systems and water resources project economics.
- Conducted a study tour of the United States and Canada to review available technology for the modeling of flow and water quality of surface systems.

1968-1970: Engineer, Technical Computing Company, Johannesburg, South Africa

- Development and application of structural analysis computer software for the design of bridge decks and pile groups, and one-dimensional tidal propagation modeling in estuaries.

REGISTRATIONS

Professional Engineer in California and seven other states.

PROFESSIONAL AFFILIATIONS

American Society of Civil Engineers
American Water Resources Association
International Mine Water Association

TECHNICAL PUBLICATIONS

Author and presenter of more than 25 publications and seminar presentations on the subjects of waste management, hydrology, and regulatory development.

A Mathematical Model to Aid Management of Outflow from the Okavango Swamp, Botswana. Journal of Hydrology, Vol. 19, No. 2, June 1973.

The Okavango Delta - Ways of Evaluating the Economic and Environmental Impact of Mass Transport of Water. Presented at the 5th Quinquennial Convention of the South African Institution of Civil Engineering, South Africa, August 1973.

A Mathematical Sediment Model for a Sea Water Intake Basin. Presented at the Conference on Marine and Fresh Water Research in Southern Africa, Port Elizabeth, South Africa, July 1976.

Lake St. Lucia - Mathematical Modelling and Evaluation of Ameliorative Measures. The Civil Engineer in South Africa, Transactions of the South African Institution of Civil Engineering, South Africa, Vol. 19, No. 4, April 1977.

Lake St. Lucia - The Computer Points the Way. African Wildlife, Vol. 31, No. 2, April/May 1977.

Mathematical Modelling of Water Level and Salinity Regions in Some Southern African Lake and Estuary Systems. Presented at the Seventeenth Congress of the International Association for Hydraulic Research (IAHR), Baden-Baden, Federal Republic of Germany, August 1977.

Regional Flood Frequency Analysis for New Brunswick. Presented at the Canadian Hydrology Symposium: 77-Floods, in Edmonton, Alberta, Canada, August 1977.

A Systematic Approach to Flood Risk Mapping. Presented at the International Symposium on Risk and Reliability in Water Resources, in Waterloo, Ontario, Canada, June 1978.

Modelling the Water and Salt Balance in a Shallow Lake. Ecological Modelling, Vol. 4, 1978, pp. 21-235.

Aspects of Phosphogypsum Waste Disposal. Presented at the Seventh Annual Madison Waste Conference, Dept. of Engineering and Applied Science, University of Wisconsin-Extension, Madison, Sept. 11-12, 1984.

Cyanide Control Options - Lessons From Case Histories. Presented at the Tucson Cyanide Conference, December 1985.

Legal Allocation of Augmented Water Supply Due to Silvacultural Activity in the Upper Rio Grande River Basin. Fourth International Hydrology Symposium on "Multivariate Analysis of Hydrologic Process: Stochastic-Deterministic," Colorado State University, Fort Collins, Colorado, July 15-17, 1985.

Introduction to Evaluation, Design and Operation of Precious Metal Heap Leaching Projects, Editor and Author of Chapter on "Surface Water Balance," 1988.

Management for Hazardous Waste Liability at Mining Sites. Colorado State University Symposium, January 1991.

Mine Waste Management. Editors: I.P. Hutchison and R.D. Ellison. Lewis Publishers, Inc. 1992. pp. 652.

Summitville Mine - Remedial Alternatives Identification and Evaluation. I.P. Hutchison, Michael L. Leonard, Sr. and David P. Cameron. Summitville Forum 95: A Forum held in Conjunction with Tailings and Mine 1995, Colorado State University, Fort Collins, Colorado, January 1995.

P-Gen/Résumés/ExWi (3/97)

ATTACHMENT B

ATTACHMENT B: REFERENCES

GSi, 1997:	GSi/water. *Ground Water Data* . Collected in 1996. 1997.
Hsieh et al., 1985:	Hsieh, P.A. and Neuman, S.P., "Field Determination of the Three Dimensional Hydraulic Conductivity Tensor of Aniosotropic Media". *I, Theory: Water Resources Research*, v.21. pp. 1655-1665. 1985.
Hubbert, 1956:	Hubbert, M.K., *Darcy's Law and the Field Equations of the Flow of Underground Fluids: Trans. America. Inst. Met. Engrs.,* v.207, pp. 222-239. 1956.
Kelsey Deposition, 1977:	Kelsey, Richard K., P.E. Deposition. Taken by Richard E. Schwartz. April 7, 1997.
Kelsey, 1997:	Kelsey, Richard K., P.E. *Expert Report.* March 14, 1997.
Long et al., 1982:	Long, J.L.S., and others, "Porous Media Equivalents for Networks of Discontinuous Fractures", *Water Resources Research*, v.18, pp. 645-658. 1982.
Mink Deposition, 1997:	Mink, Leland Leroy, Ph.D., P.G. Deposition. Taken by R. Timothy McCrum. April 8, 1997.
Mink, 1997:	Mink, Leland Leroy, Ph.D., P.G. *Expert Report.* March 13, 1997.
Molycorp, 1997:	Molycorp, Inc. Data provided by Molycorp, Questa. 1997.
Molycorp, Undated:	Molycorp, Inc. *Stormwater Pollution Prevention Plan.* Undated.
Moores, 1993:	Moores, Eldrige E. and Robert Twiss. *Structural Geology.* W.H. Freeman & Company, New York, 1993.
NMED, 1996:	Slifer, Dennis. *Red River Groundwater Investigation.* New Mexico Environment Department Surface Water Quality Bureau. March 1996.
Shoemaker Deposition, 1997:	Shoemaker, David. Deposition. Taken by Eric Ames. January 22, 1997.
SPRI, 1995:	South Pass Resources Inc. *Progress Report on the Geology, Hydrogeology And Water Quality of the Mine Area* . Taos County, New Mexico, 1995.
SRK, 1995:	Steffen, Robertson and Kirsten. *Questa Molybdenum Mine: Geochemical Assessment and Preliminary Closure Plan.* April 13, 1995.
USGS, 1988:	USGS. *Rio Grande Basin: Red River Seepage Investigation.* 1988.

Vail, 1993: Vail Engineering, Inc. *Interim Study of the Acidic Drainage to the Middle Red River, Taos County, New Mexico.* July 9, 1993.

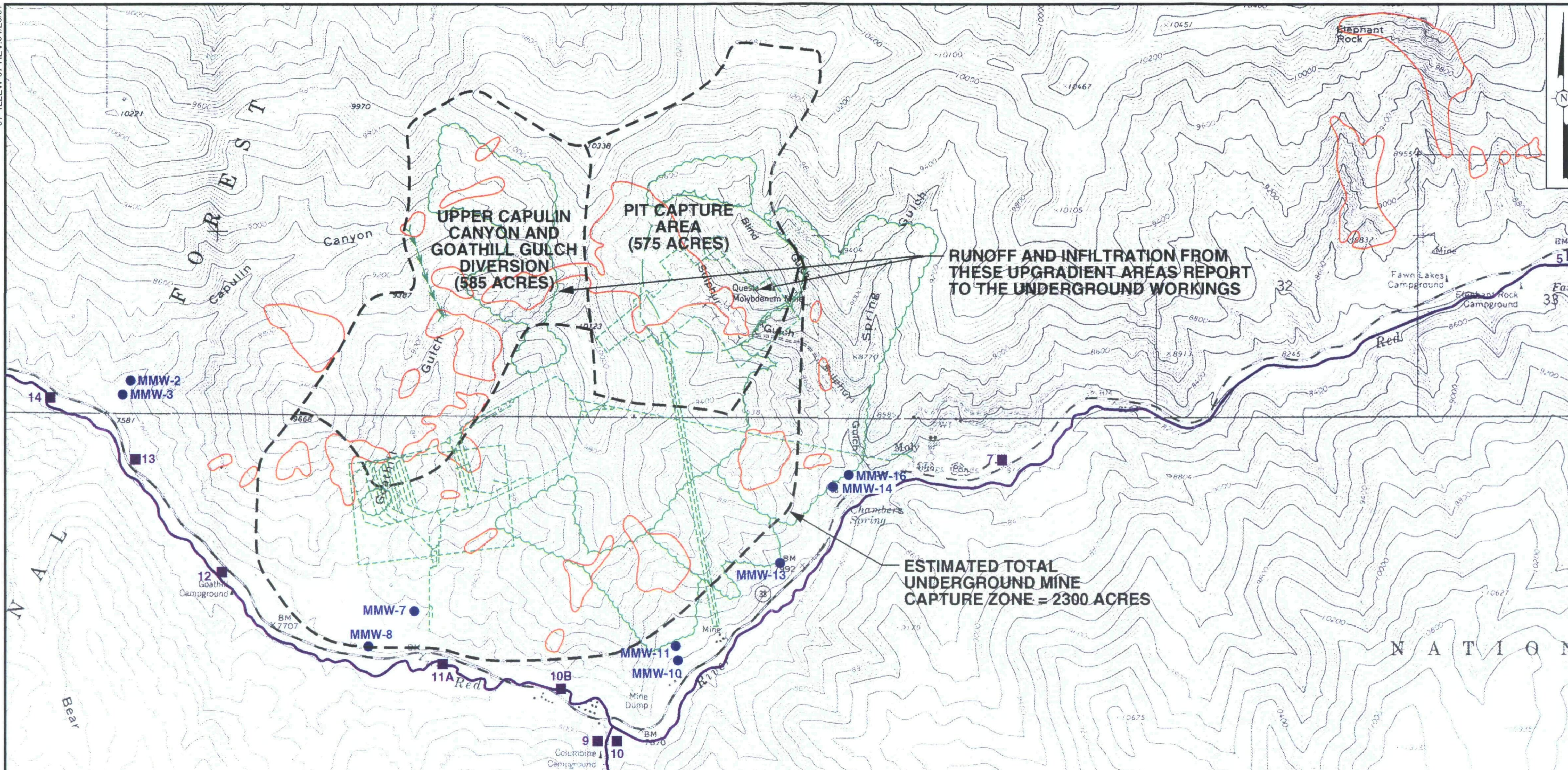
Williams Deposition, 1997: Williams, Barbara Cook, Ph.D., P.E. Deposition. Taken by Richard Schwartz. Volume I. April 8, 1997.

Williams, 1997: Williams, Barbara Cook, Ph.D., P.E. *Expert Report.* March 13, 1997.

Woodward-Clyde, 1995: Woodward-Clyde Consultants. *Red River Surface Water Investigation Report November 1995 Molycorp Questa Mine, Questa, New Mexico.* June 1996.

ATTACHMENT C

97-122EW-07 REV 04/23/97



LEGEND

- MONITORING WELL
- RED RIVER SAMPLE LOCATION
- UNDERGROUND MINE WORKINGS AND OPEN PIT
- SCAR AREAS (SRK, 1995)
- OVERBURDEN DISPOSAL PILES (SRK, 1995)
- ADIT

0 2000 4000 FEET
SCALE

REFERENCE: U.S.G.S. TOPOGRAPHIC MAPS OF QUESTA AND RED RIVER, NEW MEXICO DATED 1963.

ATTACHMENT C

MINE AREAS

TRC ENVIRONMENTAL SOLUTIONS, INC.

TRC Environmental Solutions Inc.

Molycorp, Inc.
A Unocal Company
P.O. Box 469
Questa, New Mexico 87556
Telephone (505) 586-7626
Facsimile (505) 586-0811

UNOCAL 76
MOLYCORP

Geyza I. Lorinczi
Chief Geologist/Environmental Manager

Mr. Sharpe -
The enclosed recent reports are for your review in connection with the upcoming inspection.
Please bring them with you on Sep. 8th, for these are my copies.
We can provide you with any or all of these reports if you so desire. Regards, GIL

NMR 054 223

AQUATIC BIOLOGICAL ASSESSMENT
OF THE
RED RIVER, NEW MEXICO, IN THE VICINITY OF THE QUESTA MOLYBDENUM MINE

April 1997

CHADWICK

ECOLOGICAL

CONSULTANTS, INC.

AQUATIC BIOLOGICAL ASSESSMENT

OF THE

RED RIVER, NEW MEXICO, IN THE VICINITY OF THE QUESTA MOLYBDENUM MINE

Prepared for:

MOLYCORP, Inc.
Questa, New Mexico

April 1997

Prepared by:

CHADWICK ECOLOGICAL CONSULTANTS, INC.
5575 S. Sycamore St., Suite 101
Littleton, Colorado 80120

TABLE OF CONTENTS

INTRODUCTION

The purpose of this report is to assess the aquatic biological conditions in the Red River in the vicinity of the Molycorp, Inc. Questa Molybdenum Mine. More specifically, the objective is to evaluate the impact of the open pit mine and waste rock piles on the fish and benthic invertebrate populations of the Red River.

The Questa Molybdenum Mine began operations in 1919, using underground mining methods (Schilling 1990). Late in 1965 the mine initiated open pit mining operations, and continued until 1983 (Slifer 1996). Tailings from the mill are piped down the valley to tailings ponds near Questa (Fig. 1). Waste rock was deposited near the open pit on Molycorp property in areas drained by Spring Gulch, Sulphur Gulch, Goathill Gulch, and Capulin Canyon. Claims have been made that the open pit mining operations and waste rock dumps have had a detrimental effect on the aquatic biota of the Red River adjacent to and downstream of this portion of the Molycorp property (Slifer 1996). The focus of this report is to evaluate whether the open pit mine and waste rock dumps have in the past, or are now, actually causing a measurable negative impact to the fish and benthic invertebrate populations in this section of the Red River.

The approach taken in this report is to review all available historical data on the fish and benthic invertebrate populations of the Red River, from upstream of the Town of Red River downstream to its confluence with the Rio Grande River (Fig. 1). In addition, fish population sampling in the Red River was conducted by Chadwick Ecological Consultants, Inc., on March 31 through April 3, 1997. This recent information is also included in this report.

The scope of this report is limited to the interpretation of the available aquatic biological data relative to assessing the impacts of the open pit and the waste rock dumps. For the purposes of this report, the baseline period refers to the period prior to 1966. Fish data collected in 1960 by the New Mexico Department of Game and Fish (NMDGF 1960) and benthic invertebrate data collected in 1965 by the U.S. Department of Health, Education and Welfare (USDHEW 1966) provide "baseline" data for temporal comparisons to evaluate the potential impacts of the open pit mining operations.

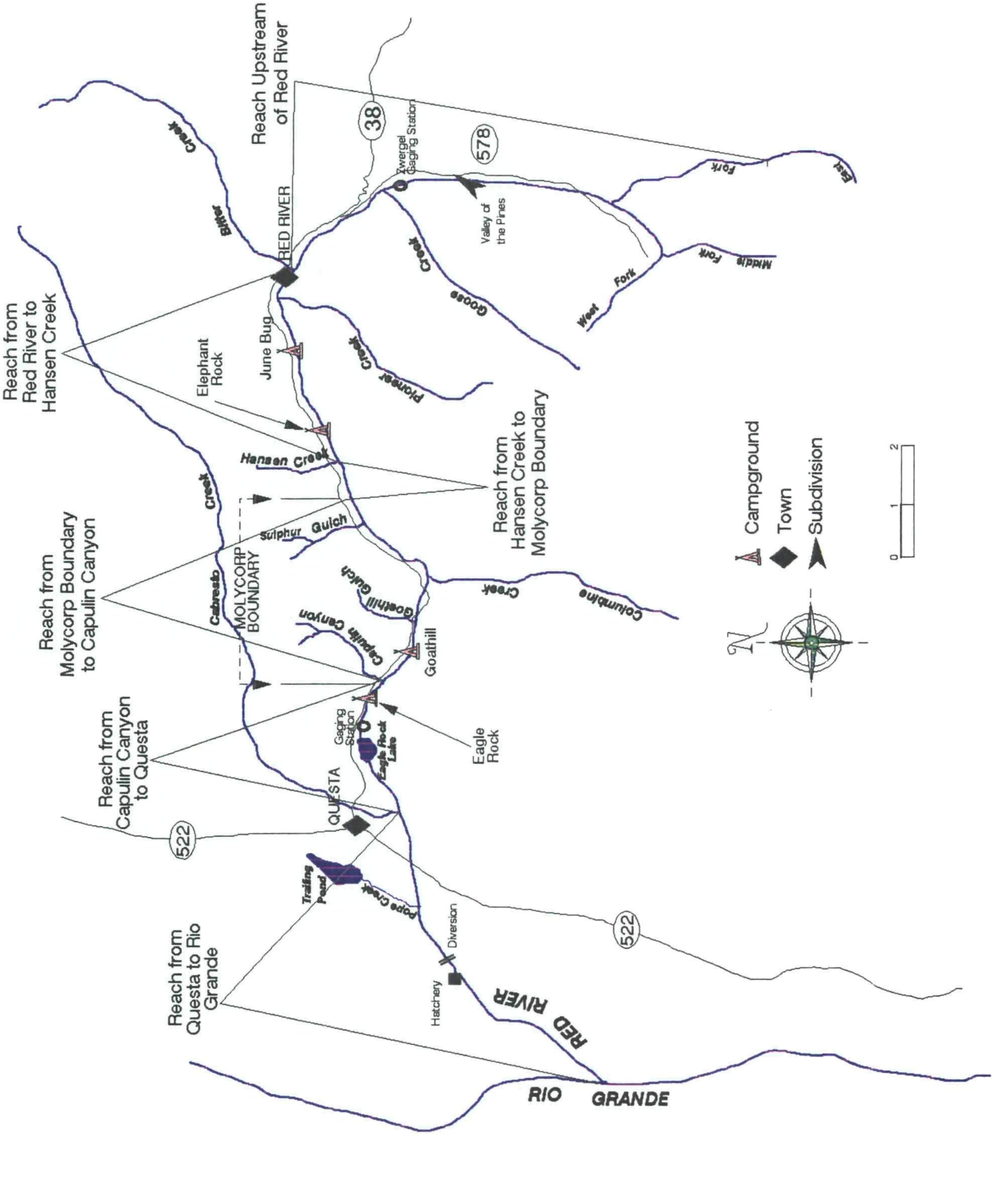


FIGURE 1: Red River Study Area with the six river reaches used in this report.

The most recent data, defining "present" conditions, include the fish data collected during March 31 through April 3, 1997, by Chadwick Ecological Consultants, Inc. (presented in this report), and benthic invertebrate data collected in December, 1995, by New Mexico Environmental Department (NMED) personnel and analyzed for Molycorp by Woodward-Clyde (1996). These two sets of data represent present conditions as defined in this report.

The most recent data are compared to the baseline data to evaluate the present day impact of the inactive open pit mine and waste rock piles on the aquatic biota. Data from the intervening years was used to further evaluate longitudinal trends in the aquatic biota, to assess past impacts of open pit mining operations, and to aid in the explanation of temporal trends between the 1960's and the 1990's.

The historic and present data indicate that trout species comprise the vast majority of fish in the Red River. Therefore, trout species are the focus of this report. Potential impacts to trout populations can be grouped into two general categories: physical impacts to habitat, and chemical impacts to water quality. Physical impacts indirectly affect trout by rendering the habitat of a river more, or less, suitable for trout, through channel alterations such as channelization, widening of a channel, disruption of the substrate, the addition of sediment, etc. In the case of the Red River, the most likely physical impact appears to be sedimentation and increased total suspended solids (TSS). Sedimentation involves the introduction of fine-grained soil particles into a stream (sand, silt, clay). In addition, particulate metal precipitate can also settle on the stream bottoms. These small particles and precipitate clog the interstitial spaces between larger rock particles (gravel, cobble, boulders) causing the larger rock particles to become "embedded." This renders the substrate unsuitable for the incubation of trout eggs, and can also render the substrate unsuitable for trout food—benthic invertebrates (Waters 1995). Turbid water (due to suspended solids or precipitate) also may reduce the visibility and impair the ability of trout to feed and may result in other sub-lethal effects (Johnson *et al.* 1987, McLeay *et al.* 1987, Farnworth *et al.* 1979, Rosenberg and Snow 1975, Gammon 1970, Wallen 1951). In effect, sedimentation may not be toxic to trout themselves, but may limit the suitability of the habitat for sustaining trout.

Water quality may affect trout populations through direct toxicity to individual trout. In less severe cases, sub-lethal effects of water quality may also occur, resulting in reduced reproduction, reduced health of individual trout, and avoidance by trout of sections of river that have elevated levels of chemical constituents (Atchison *et al.* 1987, Giattina *et al.* 1982, Sprague 1968).

Benthic invertebrates are excellent indicators of water quality in a river. Benthic invertebrate populations have characteristics that render them very useful in interpreting the magnitude and form of water quality impacts (Rosenberg and Resh 1993, Heliövaara and Väisänen 1993, DeShon 1995, Bode and Novak 1995). For example, benthic invertebrate populations are commonly comprised of several dozen different taxa, each with different tolerances to water quality constituents. The presence or absence of individual taxa allows an interpretation of the source of a water quality impact. Also, invertebrates are not very mobile and must endure the short-term water quality changes that occur in a section of river, unlike fish which can migrate long distances in a short period to avoid water quality changes. Also, invertebrates commonly have a life cycle of one to two years; their populations and community structure integrate the water quality history that occurs over this period. Finally, invertebrates are relatively easy to sample and identify, making them suitable for field studies, replicate sampling, and statistical evaluations.

Benthic invertebrates are commonly used to monitor stream systems where man-made disturbance has the potential to degrade water quality (Chadwick *et al.* 1986, Chutter 1969, Nelson and Roline 1993). Common responses to these disturbances can include decreased total abundance, decreased number of species, and a shift from a community of sensitive species to a community of tolerant species (Chutter 1969, Clements 1994). Sensitive species in mountain stream communities include mayflies (Ephemeroptera), stoneflies (Plecoptera), and caddisflies (Trichoptera), which are referred to as the "EPT" taxa (Plafkin *et al.* 1989). Tolerant stream species can include some species of midges (Chironomidae) and segmented worms (Oligochaeta).

Physical impacts directly affect benthic invertebrates by precluding their survival in the substrate of the river bottom. Physical impacts that directly affect invertebrates include sedimentation, high flows, high TSS, desiccation, disruption of the substrate, etc. In the case of the Red River, the most likely physical impact appears to be sedimentation. Benthic invertebrates generally live in the interstitial spaces between larger sized bottom substrate particles (gravel, cobble, boulders). As these interstitial spaces become filled with sediment (sand, silt, clay, precipitate), the substrate is no longer suitable for sustaining many species of benthic invertebrates (Waters 1995). Sediment impacts to benthic invertebrate populations usually result in lower density of invertebrates (Waters 1995, Culp *et al.* 1986, Rosenberg and Snow 1975), but the number and diversity of taxa sometimes remains relatively high (Farnworth *et al.* 1979). The number of taxa may remain high because there are usually a few interstitial spaces that remain open, especially in faster-flowing riffle sections of a river, which can support invertebrates.

Water quality may also directly affect benthic invertebrate populations through toxicity to individual invertebrates. Water quality impacts usually result in lower density, and possibly lower number of taxa, of invertebrates; although in some cases where dissolved metals are elevated, diversity indices can remain relatively high (Chadwick and Canton 1984, Chadwick *et al.* 1986). Impacts to water quality can also reduce the number of sensitive EPT taxa (Clements 1994).

HISTORICAL DATA SOURCES

Fish Data

Listed below are the available historical fish data sources included in this report. The list includes the year of data collection, a brief description of the document, and the literature citation of the document. The majority of the fish data were collected by NMDGF.

Date	Topic	Citation
1960	Stream Survey Forms	NMDGF (1960)
1974	Memo to R.L. Brashears, dated 24 October 1974	Patterson (1974)
1975	Memo to Bob Patterson, dated 10 November 1975	Parish (1975a)
1976	Memo to Red River File, dated 19 July 1976	Parish (1976a)
	Memo to Red River File, dated 8 September 1976	Parish (1976b)
1977	Memo to Jim Yarbrough, dated 22 April 1977	Parish (1977a)
	Memo to Jim Yarbrough, dated 9 May 1977	Parish (1977b)
1978	Memo to Bob Patterson, dated 19 July 1978	Parish (1978a)
	Memo to Bob Patterson, dated 13 September 1978	Parish (1978b)
1979	Memo to Herb Garn, dated December 3, 1979	Parish (1979)
1980	U.S. EPA Water Quality Assessment	Melancon *et al.* (1982)
1981	Memo to Mike Hatch, dated 29 October 1984	Akroyd (1984)

Date	Topic	Citation
1983	Memo to Dick McCleskey, dated 20 September 1983	Patterson (1983)
1984	Memo to Dick McCleskley, dated 29 February 1984	Patterson (1984)
1984	Memo to Mike Hatch, dated 29 October 1984	Akroyd (1984)
1985	Memo to Mike Hatch, dated 21 August 1985	Akroyd (1985)
1986	Memo to Mike Hatch, dated 5 January 1987	Akroyd (1987a)
1987	Memo to Mike Hatch, dated 6 October 1987	Akroyd (1987b)
1988	Memo to Michael Hatch, dated 29 November 1988	Akroyd (1988)
1995	New Mexico Dept. of Game and Fish Performance Report	Akroyd (1996)
1996	New Mexico Dept. of Game and Fish Performance Report	Akroyd (1997)

Benthic Invertebrate Data

Listed below are the available historical benthic invertebrate data sources included in this report. The list includes the year of data collection, a brief description of the document, and the literature citation. The benthic invertebrate data sources include a variety of different agencies and organizations.

Date	Topic	Citation
1960	Stream Survey Forms	NMDGF (1960)
1965	Water Quality Survey	USDHEW (1966)
1970	Water Quality Survey	USEPA (1971)
1971	Limnological Report to Molycorp	Pennak (1972)
1976	Limnological Report to Molycorp	Pennak (1976)
1977	Limnological Report to Molycorp, March	Pennak (1977a)
	Limnological Report to Molycorp, October	Pennak (1977b)
1978	Limnological Report to Molycorp	Pennak (1978)
1979	Limnological Report to Molycorp	Pennak (1979)
1980	Site Specific Water Quality Assessment	Melancon *et al.* (1982)
1981	Limnological Report to Molycorp	Pennak (1981)
1982	Limnological Report to Molycorp	Pennak (1983)
1983	Limnological Report to Molycorp	Pennak (1984)
1984	Intensive Survey of the Red River	Jacobi and Smolka (1984)
1985	Intensive Survey of the Red River	Smolka and Jacobi(1986)
1986	Intensive Survey of the Red River	Smolka and Tague (1987)
1988	Aquatic EcoSystem Survey	ENSR (1988)
1988	Intensive Survey of the Red River	Smolka and Tague (1989)
1992	Special Water Quality Survey	Smolka (1993)

STUDY AREA

The study area of this report includes the Red River from its headwaters to the confluence with the Rio Grande. The Molycorp Questa Molybdenum Mine is adjacent to the north bank of the Red River in its middle reaches, between the towns of Red River and Questa (Fig. 1).

Reach Descriptions

In order to organize the available historical fish and benthic invertebrate data, the Red River has been segmented into six reaches (Fig. 1). These reaches are used to group data for historical sampling sites into distinct, biologically significant parts of the river which contain roughly similar characteristics of channel morphology, habitat, potential impacts, etc. This allows a more focused interpretation of the historical data. Descriptions of the six reaches that follow are based on several field trips in March 1997 by Chadwick Ecological Consultants, Inc. personnel.

Upstream of Red River

This reach the Red River includes its headwaters downstream to the Town of Red River. There is some residential development in this portion of the river, in the form of vacation homes (e.g. Valley of the Pines subdivision) and commercial lodges, but not to the extent present in the Town of Red River. Stream shading from coniferous trees and shrubs is extensive in this reach. Stream flows are lower compared to downstream reaches, and the water is clear (Fig. 2). We observed that the stream substrate in this reach exhibited little accumulation of fine silt and sand, with low embeddedness. Water depths are variable in this reach, with a mixture of shallow riffle areas and deeper runs and pools (Fig. 3). This reach provides good habitat for the different age classes of trout. For example, young trout require the shallow areas to feed and to escape predators. The older, larger trout, in contrast, require deeper water for cover and to maintain position in the stream. The reach upstream of the Town of Red River provides this habitat variability.

FIGURE 2: Red River just upstream of the Town of Red River, New Mexico, March 16, 1997.

FIGURE 3: Red River at upstream end of the Town of Red River, March 18, 1997.

Red River to Hansen Creek

This reach extends from the Town of Red River downstream to just upstream of the confluence with Hansen Creek. Field observations in March 1997 indicated that this section begins to exhibit a reduction in water clarity and an increase in sediment deposition. Bitter Creek contains historical mining operations and natural hydrothermal scars, which apparently contribute sediment to the Red River. Channelization in some areas in the Town of Red River straightens the stream channel and decreases the variability in stream depths (Fig. 4). Water is still reasonably clear in the portion of this reach in town. Downstream of the Town of Red River, water clarity decreases (Fig. 5), due to factors which include non-point source runoff from the Town of Red River, erosion from highway banks and other disturbed areas, the outfall of the town's sewage treatment facility, and runoff from the natural hydrothermal scar drained by Hot-n-Tot Creek (Fig. 6). The substrate in the portion of this reach downstream of town becomes more embedded compared to the uppermost reach, apparently due to these natural and man-made impacts. Downstream of the Town of Red River, water depths become more variable compared to sections in town, providing potential habitat for the various age classes of trout. Shading from trees is limited in the section of the river near town, but increases in the section downstream of town.

FIGURE 4: Red River in the downstream end of the Town of Red River, March 5, 1997.

FIGURE 5: Red River just downstream of the Town of Red River, March 26, 1997.

FIGURE 6: Culvert under Highway 38 for Hot-n-Tot Creek, March 18, 1997.

Hansen Creek to Molycorp Boundary

This reach extends from the confluence with Hansen Creek downstream to the eastern edge of the Molycorp property boundary. Observations indicated a further reduction in water clarity in this reach. Water depths are variable, providing a mix of shallow riffle areas and deeper runs and pocket pools. Shading in this reach is comparable to the reach upstream of the Town of Red River. The major characteristic of this reach is the inflow of Hansen Creek, which drains a large area of hydrothermal scarring (Fig. 7). Runoff from this scarring carries sediment into the Red River, creating a relatively large alluvial fan (Fig. 8). We observed that the introduced sediment dramatically increases embeddedness and decreases water clarity, essentially covering many of the larger substrate particles in areas of reduced water velocities immediately downstream of Hansen Creek (Figs. 9 and 10).

In addition to sediment inputs from Hansen Creek, Hansen Spring also apparently introduces substances to the Red River in this reach. This spring is located in an overflow channel adjacent to the Red River, and appeared to input directly into the Red River. Its channel contained a very evident white precipitate (Fig. 11).

FIGURE 7: Hansen Creek and hydrothermal scar upstream of Highway 38, March 18, 1997.

FIGURE 8: Hansen Creek alluvial fan at confluence with Red River, March 18, 1997.

FIGURE 9: Red River just downstream of Hansen Creek, March 5, 1997.

FIGURE 10: Red River downstream of Hansen Creek near Hansen Spring, March 18, 1997.

FIGURE 11: Hansen Spring in overflow channel of Red River, March 18, 1997.

Molycorp Boundary to Capulin Canyon

This reach extends from the eastern Molycorp property boundary downstream to just upstream of the confluence with Capulin Canyon. Water depths in this reach are a combination of shallow riffles and deeper runs and plunge pools. Substrate particles are larger in this reach compared to upstream reaches, being dominated by large cobble. Observations of the stream channel indicated embeddedness is considerably higher than in the reach upstream of town, but not as high as in the reach just downstream from Hansen Creek. Similar to the next two upstream reaches, water clarity is reduced (Fig. 12). The discolored appearance of the water observed in the reach below Hansen Creek and Hansen Spring is also evident in this reach.

This reach contains the confluence with Columbine Creek, which joins the Red River from the south side of the valley. Columbine Creek is a small, clear stream (Fig. 13) that apparently acts to dilute the compounds present in the Red River.

FIGURE 12: Red River at Goathill Campground downstream of Columbine Creek, March 5, 1997.

FIGURE 13: Columbine Creek upstream of confluence with Red River, March 25, 1997.

Capulin Canyon to Questa

This reach extends from the confluence with Capulin Canyon downstream to just upstream of the confluence with Cabresto Creek, near the town of Questa. As with the reach from Hansen Creek to the Molycorp eastern property boundary, a major feature in this reach is a natural hydrothermal scar; in this case, the one drained by Capulin Canyon. Field observations in March 1997 indicated that the mouth of Capulin Canyon is similar to Hansen Creek in appearance, with loose sediment deposited in the channel. Capulin Springs also enter the Red River in this reach. These seeps also apparently introduce substances to the Red River, including those producing white precipitate.

Water in this reach continues to exhibit reduced clarity (Figs. 14 and15). The predominantly cobble substrate exhibits sedimentation in the channel, but not as much as the two reaches immediately upstream. Water depths provide a mix of shallow and deeper areas, and cover consisting of overhanging banks and pocket water is present. Stream shading is provided by willows and pines along this reach.

FIGURE 14: Red River 0.5 mi downstream of Capulin Springs, upstream of the Questa Ranger Station, March 5, 1997.

FIGURE 15: Red River just upstream of Cabresto Creek, March 5, 1997.

Questa to Rio Grande

This reach extends from the confluence with Cabresto Creek, near the town of Questa, downstream to the confluence of the Red River and the Rio Grande. At the upper end of this reach, Cabresto Creek (Fig. 16) adds clear, diluting flows to the Red River. The river valley widens at Questa, and portions of this reach through Questa have areas of unstable stream banks (Fig. 17), which contribute to less variability in water depths compared to downstream portions of this reach. The cobble substrate exhibits less embeddedness compared to the other reaches downstream of the Town of Red River. The river valley subsequently narrows again upstream of the state fish hatchery, and remains a narrow canyon down to the Rio Grande.

Water clarity near the fish hatchery appeared to be somewhat better than the reaches immediately upstream, with less of a milky white color. The outfall from the hatchery also acts as a dilution effect to the Red River (Fig. 18).

Water depths are more variable, with deeper pool habitat in the section of this reach from just upstream of the hatchery downstream to the Rio Grande. Although shading from trees is less than that of upstream reaches, the steep canyon walls in the lower half of this section provide shading.

FIGURE 16: Cabresto Creek upstream of the Red River, March 5, 1997.

FIGURE 17: Red River downstream of the Highway 522 bridge, March 25, 1997.

FIGURE 18: Red River at the Red River Fish Hatchery, March 5, 1997.

Site Descriptions

Fish collection study sites sampled by Chadwick Ecological Consultants, Inc., in the spring of 1997 are described below and are included in Fig. 19. Study sites from historical fish studies are also briefly described below. Due to the large number of historical study sites, they are not individually shown on the figures, but have been grouped into the distinct, biologically significant reaches of river as shown (Figs. 1 and 19).

<u>1997 Fish Data Collection</u>

Elevations for the portion of the Red River sampled in the present study ranged from approximately 8,900 feet upstream from the Town of Red River down to approximately 7,120 feet, at a point 0.3 miles upstream from the diversion for the Red River fish hatchery. Stream gradients within the study reach are highest upstream from the Town of Red River, moderate from the Town of Red River downstream to Questa, and lowest from the town of Questa downstream to near the fish hatchery.

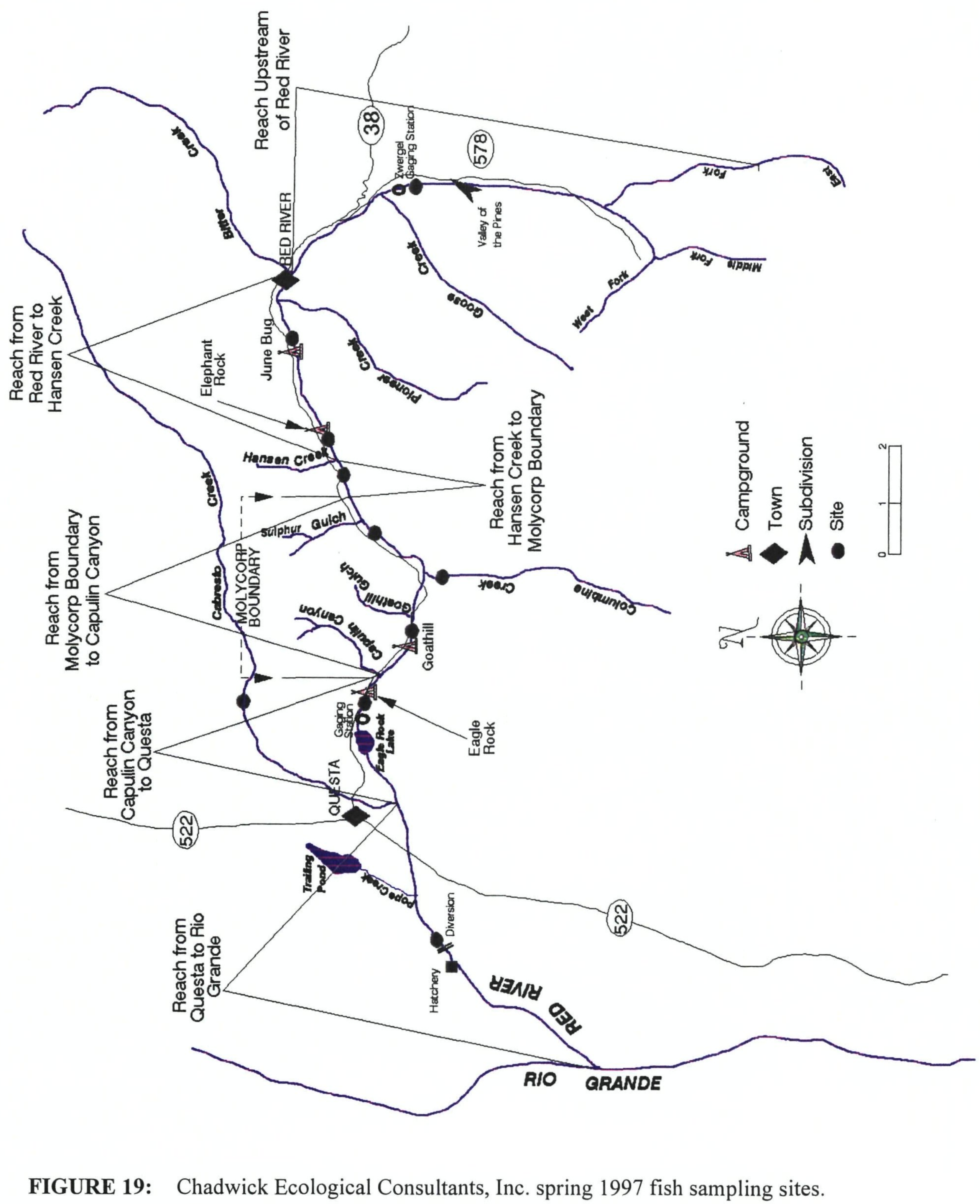


FIGURE 19: Chadwick Ecological Consultants, Inc. spring 1997 fish sampling sites.

Capulin Canyon to Questa

In the reach of the Red River from Capulin Canyon downstream to Questa, rainbow and brown trout and a few white suckers have been collected (Appendix A, Table A1). Most of the trout caught were stocked rainbow trout (Table 7). The brown trout were apparently sustained by immigration from adjacent sections of the river.

Abundance of trout was consistently low at the Questa Ranger Station site. In the 1970's, stocked rainbow trout were present at the most downstream section of this reach, at the Head of Eagle Rock Lake sampling site.

No sampling site was located in this reach of the Red River in 1960, and sampling was not initiated in this reach until the mid 1970's. The baseline trout populations in this reach are uncertain, but probably exhibited a low abundance of trout. This is evident from the low abundance in upstream reaches in 1960, and the low abundance present in the 1970's and 1980's.

TABLE 7: Historical fish collection data for the reach of the Red River from Capulin Canyon downstream to Questa. First pass data only.

Site, Date	Total # Collected	Total #/Mile	% RBT
Near Mouth of Bear Canyon			
Nov. 1975	2	40	100
April 1977	0	0	0
July 1978	14	140	86
Eagle Rock Campground			
July 1976	17	228	76
Questa Ranger/Gaging Station			
Sept. 1988	0	0	0
Aug. 1995	0	0	0
Aug. 1996	2	32	0
Head of Eagle Rock Lake			
Nov. 1975	10	200	50
July 1976	35	700	46
April 1977	12	120	0

This reach of the river appears to have low suitability to maintain trout populations. The most apparent reason for this low suitability appears to be excessive sediment conditions (both physical sediment and particulate precipitate). In addition, some effects of chemical stress may be present from dissolved aluminum. The influence of Capulin Canyon appears to preclude improvements in the suitability of this reach of the river for trout.

Questa to Rio Grande

The reach of the Red River from Questa downstream to the confluence with the Rio Grande consistently supported rainbow and brown trout (Appendix A, Table A1). The abundance of these two species has been evenly mixed over the years (Table 8). A few white suckers and two chubs were also collected. The rainbow trout were probably maintained by stocking; brown trout were probably maintained by natural reproduction.

TABLE 8: Historical fish collection data for the reach of the Red River from Questa downstream to the Rio Grande. First pass data only.

Site, Date	Total # Collected	Total #/Mile	% RBT
SH 522 Bridge			
Sept. 1980	46	815	78
Upstream of hatchery diversion			
Oct. 1960	6	317	0
July 1976	32	640	69
Sept. 1980	23	405	26
Nov. 1986	28	687	65
Sept. 1987	12	316	8
Sept. 1988	49	1,293	27
Sept. 1995	29	424	55
Aug. 1996	100	1,609	14
Downstream of hatchery diversion			
July 1976	32	640	69
April 1977	126	1,260	64
Nov. 1986	47	1,241	36
Sept. 1987	36	950	8
Sept. 1988	71	1,875	34
Downstream of hatchery			
June 1981	29	290	55
Sept. 1984	37	370	38

TABLE 8: Continued.

Site, Date	Total # Collected	Total #/Mile	% RBT
Aug. 1985	16	160	6
Nov. 1986	230	2,300	47
Sept. 1987	59	590	37
Sept. 1988	130	1,300	11
Between hatchery and El Aujae Campground			
Oct. 1974	371	2,474	89
Nov. 1979	34	680	24
June 1981	70	350	66
Feb. 1984	8	80	0
Sept. 1984	75	375	19
Aug. 1985	40	200	3
Nov. 1986	224	1,120	7
Sept. 1987	120	600	11
Sept. 1988	243	1,215	0
El Aujae Campground			
Sept. 1976	55	1,100	44
June 1981	57	570	81
Sept. 1984	22	220	9
Aug. 1985	17	170	6
Nov. 1986	74	740	7
Sept. 1987	58	580	7
Sept. 1988	126	1,260	1
La Junta Point			
Nov. 1979	37	740	16
June 1981	37	370	49
Sept. 1984	34	340	9
Aug. 1985	47	470	43

A baseline abundance of 317 brown trout/mile was present during sampling in 1960 (Table 8). This abundance of fish was exceeded during almost all subsequent sampling periods at all sites. On many occasions, brown trout abundance, alone, exceeds this level, without the stocked rainbow trout. Brown trout populations in this section of the Red River appear to be healthy and self-sustaining. Abundance levels equal or exceed those that were found in the headwater reach of the river, upstream of the Town of Red River.

Historical Benthic Invertebrate Populations

Upstream of Red River

In the Red River upstream of the Town of Red River, benthic invertebrate sampling indicates the presence of healthy, diverse populations (Table 9; Appendix B, Table B1). Density was consistently higher than 1,000 invertebrates/m^2 at most sites, and the diversity indices were consistently higher than 3.0. The number of taxa varied substantially over the years. However, this may be the result of differing methods employed among the different studies.

Baseline conditions in 1965 indicate just over 1,000 invertebrates/m^2 and 20-22 taxa were present at the two sites in this reach (Table 9). Most of the taxa were EPT taxa, indicating suitable water quality and substrate conditions.

TABLE 9: Historical benthic invertebrate collection data for the reach of the Red River upstream of the Town of Red River.

Site, Date	# of Taxa	% EPT Taxa	#/m^2	g/m^2	Diversity Index
East Fork at Blue Lake Trail					
June 1960	9	78	542	--	--
Zwergel Gaging Station					
Sept. 1980	27	59	K	--	--
April 1985	27	63	2,501	--	3.60
Aug. 1986	16	69	1,567	--	3.03
Sept. 1988	28	61	2,038	--	3.77
April 1992	31	64	2,765	--	3.64
Upstream of Bitter Creek					
Nov. 1965	22	77	1,044	--	--
Nov. 1970	17	--	3,548	--	--
April 1992	29	59	3,090	--	3.45
Downstream of Bitter Creek					
Nov. 1965	20	90	1,267	--	--
Nov. 1970	16	--	2,971	--	--
April 1992	26	65	2,551	--	3.46

K = kick sample (qualitative)

Red River to Hansen Creek

In the reach of the river downstream of the Town of Red River, most population indices still indicate healthy invertebrate populations. However, a slight impairment from the conditions upstream of the Town of Red River is apparent. For example, densities are lower in many cases than in the reach upstream (Table 10), with several density values less than 1,000/m². Three of the eight calculated diversity indices are less than 3.0. These population parameters suggest some historical impairment near the Town of Red River. There was no baseline sampling location in 1965 in this reach of the Red River.

TABLE 10: Historical benthic invertebrate collection data for the reach of the Red River from the Town of Red River downstream to Hansen Creek.

Site, Date	# of Taxa	% EPT Taxa	#/m²	g/m²	Diversity Index
June Bug Campground					
Sept. 1980	25	68	K	--	--
Jan. 1984	22	68	2,071	--	3.13
Aug. 1986	21	71	1,145	--	3.33
Sept. 1988	14	64	771	--	2.59
April 1992	20	65	1,835	--	3.13
Elephant Rock Campground					
Nov. 1970	17	--	1,152	--	--
Sept. 1980	27	67	K	--	--
April 1985	21	67	916	--	3.79
Aug. 1986	23	70	2,090	--	3.15
Sept. 1988	16	62	997	--	2.92
April 1992	18	72	1,407	--	2.71

K = kick sample (qualitative)

Hansen Creek to Molycorp Boundary

Downstream of Hansen Creek the historical data indicate that invertebrate density was relatively low, compared to sites upstream of Red River. Density levels in this reach of the Red River are less than a few hundred invertebrates/m² in many cases (Table 11). This contrasts with levels of nearly 800/m² to over 2,000/m² in the reach immediately upstream (Table 10). The number of taxa is also substantially lower in this reach. For baseline conditions in 1965, this reach exhibited a significant (ANOVA, $p < 0.05$) 20% reduction in abundance, and a 37% decrease in number of taxa compared to the river upstream of the Town of Red River (Tables 9 and 11). These 1965 USDHEW data appear to contradict the conclusions of the report by USDHEW (1966), and the reiteration of these conclusions in Slifer (1996), which state that "the water is clean at all stations sampled in the study area." This USDHEW conclusion appears to have been directed toward the amount of organic pollution in the river as based on the biotic indices. In fact, the USDHEW population parameters indicate substantial impacts to invertebrate population levels downstream of Hansen Creek, even under baseline conditions.

TABLE 11: Historical benthic invertebrate collection data for the reach of the Red River from Hansen Creek downstream to the Molycorp property boundary.

Site, Date	# of Taxa	% EPT Taxa	#/m²	g/m²	Diversity Index
Upstream of Molycorp property boundary					
Nov. 1965	17	71	337	--	--
May 1971	5	60	99	1.7	--
June 1971	9	78	210	4.2	--
July 1971	9	89	109	4.0	--
Sept. 1971	9	78	90	2.7	--
Oct. 1971	4	100	29	0.8	--
Nov. 1971	10	70	160	2.9	--
Oct. 1976	--	--	562	6.0	--
March 1977	--	--	787[a]	1.7	--
Oct. 1977	--	--	56	0.7	--
March 1978	--	--	959	7.3	--
Aug. 1979	--	--	--	1.6	--
Sept. 1979	--	--	--	0.4	--
Sept. 1980	18	72	K	--	--
July 1981	--	--	--	26.5	--
Oct. 1982	--	--	--	4.4	--
Oct. 1983	--	--	--	2.7	--
Sept. 1988	16	62	1,275	--	2.82
Oct. 1988	10	90	230	--	2.92
April 1992	13	62	1,594	--	2.41

K = kick sample (qualitative)
[a] = published value miscalculated as 112/m²

The percent EPT taxa is relatively high in the samples from 1971 and in the late 1980's and early 1990's (Table 11). This suggests a physical impact to the population, such as the input of sediment from Hansen Creek. Increased sediment levels can reduce the density of invertebrates (Culp *et al.* 1986, Farnworth *et al.* 1979, Rosenberg and Snow 1975, Gammon 1970). However, periodic influx of storm flows from Hansen Creek, which would contain elevated metal levels, as well, may also be affecting this reach.

Molycorp Boundary to Capulin Canyon

The data available for the reach of the Red River from the Molycorp property boundary downstream to Capulin Canyon are very limited (Table 12). However, in most cases densities are similar to those in the reach of the river just downstream of Hansen Creek. The number of taxa appears to be slightly higher than in the reach upstream. As all of these samples were collected downstream of Columbine Creek; this suggests some improvement to the water quality and/or sediment due to Columbine Creek or through colonization by drifting invertebrates from this tributary.

TABLE 12: Historical benthic invertebrate collection data for the reach of the Red River from the Molycorp property boundary downstream to Capulin Canyon.

Site, Date	# of Taxa	% EPT Taxa	$\#/m^2$	g/m^2	Diversity Index
Downstream of Columbine Creek					
Sept. 1980	26	70	K	--	--
Upstream of Goathill Gulch					
Nov. 1965	14	71	402	--	--
Nov. 1970	11	--	933	--	--
Goathill Campground					
Oct. 1976	--	--	808[a]	6.5	--
March 1977	--	--	211	4.5	--
Oct. 1977	--	--	43	0.3	--
March 1978	--	--	1,677	32.3	--
July 1978	--	--	443	5.2	--
Aug. 1979	--	--	--	0.6	--
Sept. 1979	--	--	--	0.6	--
Sept. 1980	20	75	K	--	--
July 1981	--	--	--	3.0	--
Oct. 1982	--	--	--	1.9	--
Oct. 1983	--	--	--	1.5	--
Oct. 1988	6	83	79	--	1.96

K = kick sample (qualitative)
[a] = published value miscalculated as $763/m^2$

Baseline conditions in 1965 indicate number of taxa, percent EPT taxa, and density are similar to those in the reach downstream of Hansen Creek (Table 11). The density levels at these two sites from 1965 were not significantly different. This indicates no substantial differences in the limited suitability of these two reaches of the Red River to support invertebrates in 1965, which again appears to contradict the conclusions in USDHEW (1966), which was the source of the baseline data.

Capulin Canyon to Questa

In the reach of the Red River downstream of Capulin Canyon, low number of taxa and low density of invertebrates have historically been present (Table 13). The densities are comparable to the two reaches just upstream: the reaches downstream of Hansen Creek and on the reach adjacent to the Molycorp property. However, the number of taxa in the reach downstream of Capulin Canyon appear to be somewhat lower than in the reaches upstream. This suggests additional impacts to the invertebrate populations are occurring in this reach, possibly due to the influences of Capulin Canyon. The percent EPT taxa is comparable to all upstream reaches of the river.

Baseline conditions in 1965 indicate low number of taxa and low density (Table 13). The density at the Questa Ranger Station site in 1965 was significantly lower (ANOVA, $p < 0.02$) than that at the adjacent site upstream on the Molycorp property. This indicates that this reach of the river historically was significantly less suitable for supporting benthic invertebrates than the reach of river adjacent to the Molycorp property. These data again contradict the conclusion that biological conditions in the Red River in 1965 were of high quality (USDHEW 1966).

TABLE 13: Historical benthic invertebrate collection data for the reach of the Red River from Capulin Canyon to Questa.

Site, Date	# of Taxa	% EPT Taxa	#/m²	g/m²	Diversity Index
Eagle Rock Campground					
May 1971	5	80	31	2.9	--
June 1971	5	40	74	1.1	--
July 1971	8	50	59	2.9	--
Sept. 1971	6	67	50	1.3	--
Oct. 1971	8	88	149	3.5	--
Nov. 1971	7	71	50	2.3	--
Oct. 1976	--	--	170	1.4	--
March 1977	--	--	555[a]	7.8	--
Oct. 1977	--	--	82	2.4	--
March 1978	--	--	52	0.5	--
July 1978	--	--	490	16.3	--
Aug. 1979	--	--	--	0.2	--
Sept. 1979	--	--	--	1.0	--
July 1981	--	--	--	1.5	--
Oct. 1982	--	--	--	1.4	--
Oct. 1983	--	--	--	2.4	--
Questa Ranger/Gaging Station					
Nov. 1965	9	67	83	--	--
Nov. 1970	11	--	448	--	--
Sept. 1988	6	100	171	--	2.06
Oct. 1988	3	100	108	--	1.30
April 1992	10	60	490	--	1.18

K = kick sample (qualitative)
[a] = calculated value approximately 112/m²

Questa to Rio Grande

The historical data in the reach of the Red River downstream of Questa suggest some improvement in conditions for benthic invertebrates, compared to the reach of the river just upstream of Questa. Density of invertebrates was almost always greater than 100/m², and in many cases was at least several hundred/m² (Table 14). The number of taxa also is greater in most cases in the reach downstream of Questa, relative to the reach upstream of Questa. These improvements are probably due, at least in part, to the positive influence of the input of water from Cabresto Creek.

TABLE 14: Benthic Invertebrate collection data for the reach of the Red River from Questa downstream to the Rio Grande.

Site, Date	# of Taxa	% EPT Taxa	#/m²	g/m²	Diversity Index
SH 522 Bridge					
Nov. 1965	6	67	108	--	--
Nov. 1970	10	--	818	--	--
Sept. 1980	22	73	K	--	--
April 1985	17	59	388	--	3.48
Aug. 1986	17	71	607	--	3.34
April 1992	13	69	535	--	2.43
Upstream of Pope Creek					
May 1971	11	82	290	7.14	--
June 1971	5	40	216	3.78	--
July 1971	8	75	326	5.04	--
Sept. 1971	8	75	82	0.84	--
Oct. 1971	8	88	147	2.10	--
Nov. 1971	8	88	617	3.36	--
Oct. 1976	--	--	765	6.6	--
March 1977	--	--	2,018	17.3	--
Oct. 1977	--	--	159	1.1	--
March 1978	--	--	907	6.2	--
July 1978	--	--	211	1.8	--
Aug. 1979	--	--	--	2.4	--
Sept. 1979	--	--	--	2.0	--
July 1981	--	--	--	6.7	--
Oct. 1982	--	--	--	14.0	--
Oct. 1983	--	--	--	6.9	--
Oct. 1988	11	64	362	--	2.68
Upstream of hatchery diversion					
June 1960	12	67	1,650	--	--
Nov. 1965	10	50	291	--	--
Nov. 1970	16	--	2,759	--	--
May 1971	9	78	299	10	--
June 1971	7	71	479	16	--
July 1971	8	62	199	--	--
Sept. 1971	6	50	571	--	--
Oct. 1971	5	60	479	10.9	--
Nov. 1971	7	57	84	--	--
Oct. 1976	--	--	632	5.8	--

TABLE 14: Continued.

Site, Date	# of Taxa	% EPT Taxa	#/m^2	g/m^2	Diversity Index
March 1977	--	--	1,875	51.6	--
Oct. 1977	--	--	224	2.5	--
March 1978	--	--	1,402	18.5	--
July 1978	--	--	2,207	21.1	--
Aug. 1979	--	--	--	3.4	--
Sept. 1979	--	--	--	1.0	--
July 1981	--	--	--	4.9	--
Oct. 1982	--	--	--	2.8	--
Oct. 1983	--	--	--	6.9	--
Oct. 1988	11	64	495	--	2.56
Downstream of Hatchery					
April 1992	19	63	1,423	--	3.19
Between hatchery and El Aujae Campground					
Nov. 1965	20	50	344	--	--
Nov. 1970	19	--	3,523	--	--
Aug. 1979	--	--	--	1.7	--
Sept. 1979	--	--	--	1.4	--
July 1981	--	--	--	6.7	--
Oct. 1982	--	--	--	9.8	--
Oct. 1983	--	--	--	6.0	--
April 1985	20	75	2,047	--	2.29
Aug. 1986	17	65	1,836	--	2.70
Oct. 1988	12	58	1,973	--	1.66
La Junta Point					
Oct. 1988	10	70	K	--	--

K = kick sample (qualitative)

There is also some information that indicates conditions have improved over the last three decades. The baseline conditions at the two sites in this reach sampled in 1965 (State Highway 522 Bridge, above the hatchery diversion) indicate low numbers of taxa and low densities (Table 14). The 1965 densities in this reach were not significantly different from those in the reach upstream of Questa. However, the data from 1965 at the two sites in this reach clearly represent low densities relative to the data collected in this reach in the 1970's and 1980's.

TEMPORAL PATTERNS OF AQUATIC BIOTA

Fish

Fish collection data from 1960 were collected prior to the initiation of open pit mining, and represent baseline data. Fish collection in the spring of 1997 provide the most recent data available and allow a comparison of baseline and present conditions with which to evaluate the effects of open pit mining on the fish populations of the Red River. Also, data collected during the intervening period can be compared to investigate the trend over time.

USGS gaging records for the Red River were briefly examined for the period from 1958-1996. As fish populations can be impacted by extreme high and low flows, the flow records were evaluated in order to determine if fish collection data for the baseline period (1960) or the present (1997) were affected to any unusual degree by extremely high runoff flows or extremely low winter flows. It appears that, for several years prior to data collection in 1960, both high and low flows were not unusually extreme, and would probably not have affected resident fish populations to an unusual degree. Similarly, the flow levels over the past few years apparently have not affected fish populations sampled in 1997 to an unusual degree.

In order to make the data sets from the different periods comparable, only first pass electrofishing data were used. Also, since rainbow trout are maintained by stocking, and are not directly controlled by habitat and water quality conditions as are resident fish, rainbow trout numbers have been omitted from the comparison. The intervening period was defined as 1974 through 1988. The year 1974 represents the first available data collected after the initiation of open pit mining. Data collected in 1995 and 1996 by NMDGF were omitted from the intervening period as these two years are probably more representative of present conditions than the period between baseline and the present. All data were presented as the number of fish collected on the first pass per mile of river. For the intervening years (1974-1988), all collection sites within a reach of the river were averaged; at sites with only rainbow trout present, or with no fish collected, a value of 0 fish per mile was used in the calculations.

The Red River apparently experiences a relatively high level of recreational fishing pressure (Akroyd, R.F. 1997, personal communication). This fishing pressure is apparently dispersed throughout the length of the river from the reach upstream of Red River downstream to near the fish hatchery. Recreational fishing commonly has a substantial influence in the fish present in a reach of river, and this is probably also the case in the Red River. However, we have no information that indicates that one reach of the Red River is affected to a larger degree than others in the past or at present. Therefore, we assume that fishing pressure is affecting the different reaches of the Red River at roughly equal levels.

It has been our experience that stocked rainbow trout are more vulnerable to being caught by anglers; the resident brown trout are considerably less vulnerable. Rainbow trout commonly absorb the brunt of the fishing pressure. This was the case in the Red River based on data from 1959-1974 (Pacific 1979). Data from this period indicated that rainbow trout comprised 97% of the total fish caught by anglers; slightly less than 3% of the catch were brown trout, with a few cutthroat and brook trout also caught (Pacific 1979). Thus, the elimination of rainbow trout from the data comparisons, below, helps minimize the effects of fishing pressure in evaluating the trends in fish data discussed below.

The longitudinal trends in fish density (number of fish/mile) show a similar trend for baseline conditions (1960 data), the period during operation of the open pit mine (1974-1988 data), and present conditions (1997 data). The trends all indicate a substantial decrease in trout density downstream of the Town of Red River (Fig. 24). However, an even more dramatic decrease in trout density is evident downstream of Hansen Creek. This pattern is evident for baseline (1960) data, prior to the initiation of open pit mining, as well as the later sampling periods. The data for all three periods also show a substantial increase in trout density downstream of Questa.

A direct comparison between the data from 1960 and 1997 indicate that at all four reaches where corresponding data were collected in both years (upstream of Red River, Red River to Hansen Creek, the Molycorp property between the Molycorp property boundary and Capulin Creek, and Questa to the Rio Grande), the fish density in 1997 is higher than in 1960 (Fig. 24). Although the collection methods utilized in 1997 may have been more efficient, the higher fish densities in 1997 indicate that the Red River is at least as suitable for sustaining trout in 1997 as it was in 1960.

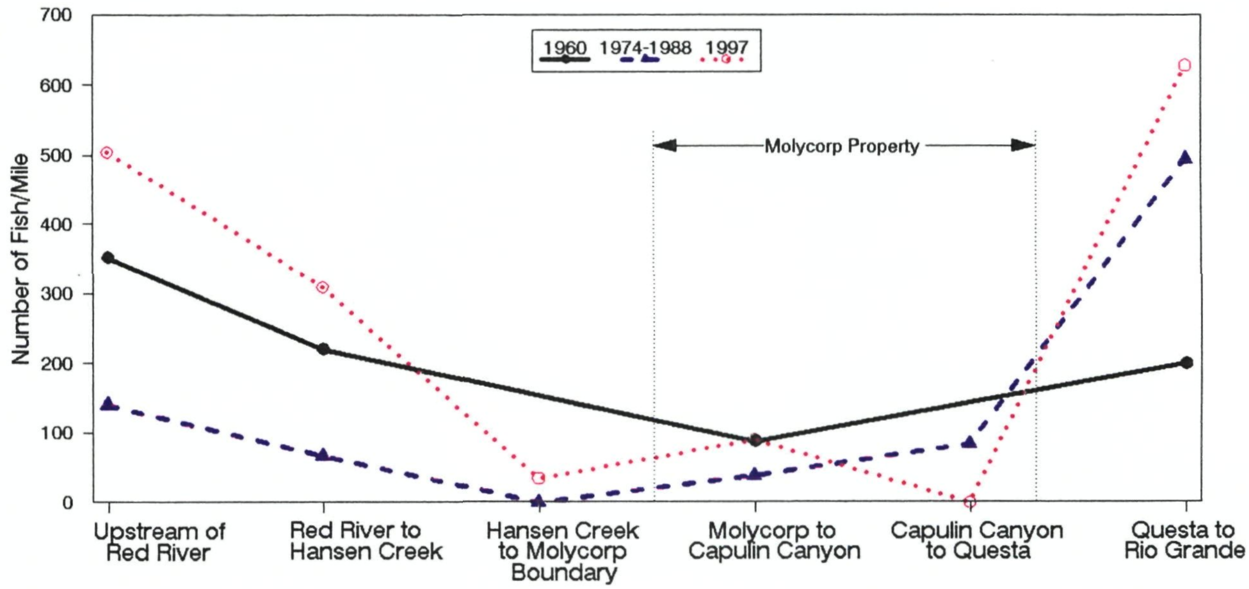


FIGURE 24: Longitudinal trends in fish density (no./mile) for baseline conditions (1960 data), open pit mine operation (1974-1988 data), and the present (1997 data). First pass data only, rainbow trout excluded.

In the reach of the Red River downstream of Capulin Canyon and upstream of Questa (the Questa Ranger Station Site), no fish were found in 1997 (Table 1), or in 1988 and 1995. In 1996, only two brown trout were collected at this site. No corresponding site was sampled in this reach of the river in 1960, or apparently prior to 1988. Therefore, no direct comparison is possible between baseline and present conditions at this site.

The direct comparison found in Slifer (1996), indicating that trout density has decreased from 572 fish per mile down to 0 fish per mile between 1960 and 1988, is an inaccurate comparison. First of all, the fish per mile figure used in Slifer (1996) from 1960 is actually data for the 1960 site located *upstream* of Columbine Creek. The 1988 data referred to by Slifer (1996) as having no fish is from a site located at the Questa Ranger Station, approximately 4.5 miles downstream of the 1960 site. As the influences of both Columbine Creek, Capulin Canyon, and other point and non-point sources of potential changes to the river occur between the location of the 1960 site and the 1988 Questa Ranger Station site, the comparison in Slifer

(1996) is misleading and inaccurate. In fact, there are no matching sites between the 1960 and 1988 studies that would allow such a comparison as made in Slifer (1996).

In addition, the 572 fish per mile reportedly collected at the 1960 site (upstream of Columbine Creek) is actually 88 fish per mile, excluding stocked rainbow trout. In 1960 (October), a single electrofishing pass was made through 300 feet of stream, and 11 rainbow and 5 brown trout were collected, for a total of 16 fish per 300 feet of stream, or 282 fish per mile actually captured. However, this number was expanded by more than 100% in an attempt to account for poor visibility at the time of sampling (Parish 1975b). The expanded number of 572 simply represents a wild guess as to the number of fish present, and is an inappropriate way to treat field data. This conclusion was also reached by NMDGF (Parish 1975b). As discussed above, for purposes of comparing resident fish rather than recently stocked fish, only the brown trout numbers actually collected were considered in this report. If this is done, the actual number is 88 fish per mile in 1960.

More importantly, the trend in trout density in 1960, 1974-1988, and 1997 data all indicate negative impacts to the trout beginning in the reach immediately downstream of the Town of Red River. A more substantial negative impact occurs downstream of Hansen Creek. The cumulative effects of these impacts reduce trout density to very low levels prior to the reach of river adjacent to the Molycorp property. Adjacent to the mine, slight increases in trout density are found. This is probably due, in part, to the positive impact on the Red River due to the input of water or migrating fish from Columbine Creek. Downstream of Capulin Canyon, the trout density is reduced even further. Downstream of Questa, the suitability of the Red River to support trout is more comparable to that found upstream of the Town of Red River.

Benthic Invertebrates

Benthic invertebrate data from early November 1965 were apparently collected prior to the initiation of open pit mining, and represent baseline data. Benthic invertebrate data collected in December 1995 represent the most recent data available and allow a comparison of baseline and present conditions with which to evaluate the effects of open pit mining on the benthic invertebrate populations of the Red River. Data available from the intervening period can also be used to investigate the long-term trend in populations.

In order to make appropriate comparisons between the data sets, the two population parameters of density (no./m^2) and number of taxa are used. These two parameters are common to most of the available data sets. Also, these two parameters are useful and commonly used in evaluating physical and chemical impacts to benthic invertebrate populations.

The longitudinal trend in benthic invertebrate density shows a general decrease from the reach upstream of Red River downstream to near Questa (Fig. 25). This trend is evident for baseline conditions (1965 data), the period during the operation of the open pit mine (1970-1992 data), and for present conditions (1995 data).

For all data sets, there is a decrease in invertebrate density downstream of the Town of Red River. There is a further decrease in density downstream of Hansen Creek. All three data sets reach their lowest density in the reach of the Red River between Capulin Canyon and Questa. Downstream of Questa all three data sets indicate a substantial increase in benthic invertebrate density. This pattern was clearly established in benthic invertebrate populations in 1965, prior to open pit mining, and continues to present.

The trend in number of taxa among the three data sets shows decreases from upstream of Red River downstream to near Questa (Fig. 26). The trend for all data sets show a substantial decrease in taxa in the reach downstream of Hansen Creek, upstream of the Molycorp mine. The decrease continues, with lowest number of taxa in the reach downstream of Capulin Canyon for the 1995 and 1970-1992 data sets. For the 1965 data set, the reach downstream of Questa exhibited the lowest number of taxa.

In all six reaches of the Red River, the present benthic invertebrate density and number of taxa are substantially higher than those of the baseline period (1965) and the period of open-pit mine operation (1970-1992 data). Although the collection and analysis methods varied between the various studies, this information suggests that the Red River is at least as suitable for sustaining benthic invertebrates at present as it was prior to open pit mining operations.

During fish population sampling for the present study, water clarity was variable between study sites. The water was very clear at the study site upstream from the Town of Red River, and moderately stained with a blush-white color roughly halfway between the Town of Red River and the Molycorp Mine property boundary. This staining was greater downstream at the U.S. Forest Service Questa Ranger Station. Water clarity near the fish hatchery increased to levels similar to the reach of the Red River upstream of the Molycorp property.

Overall channel morphology and gross habitat features relative to the suitability of the Red River for sustaining trout are similar from the upper reaches of the river downstream to the Rio Grande. Although specific habitat characteristics of the river, such as gradient, sinuosity, width, etc., vary along the river, a similar riffle-run-pool character is present along its entire length. Cover consisted of pocket water, undercut banks, snags, overhanging vegetation, and pools throughout.

Study site locations for spring 1997 fish sampling are as follows:

Red River

Upstream of Town of Red River	Located approximately 0.6 miles upstream from Goose Creek, 0.2 miles upstream from the gaging station at an elevation of approximately 8,900 feet.
June Bug Campground	Located near the upstream end of June Bug Campground at an elevation of approximately 8,530 feet.
Downstream of Elephant Rock Campground, upstream from Hansen Creek	Located 0.4 miles downstream from Elephant Rock Campground at an elevation of approximately 8,360 feet.
Downstream of Hansen Creek, upstream of mill	Located 0.8 upstream miles upstream from mill access road, 0.7 miles downstream from Hansen Creek, at an elevation of approximately 8,200 feet. This site corresponds to the "Bobita Campground" site of the New Mexico Game and Fish Department.
Downstream of mill, upstream of Columbine Creek	Located 1.1 miles downstream from mill access road at an elevation of approximately 8,100 feet.
Goathill Campground	Located at the upstream end of Goathill Campground at an elevation of approximately 7,670 feet.

Upstream of Questa Ranger Station	Located 0.4 miles upstream from ranger station access road, just upstream from where tailings pipes cross over the Red River. The elevation of this site was approximately 7,480 feet.
Upstream of hatchery diversion	Located 0.3 miles upstream of the Red River fish hatchery diversion, at an elevation of approximately 7,120 feet.

Tributaries

Columbine Creek	Located approximately 400 yards upstream from its confluence with the Red River, at an elevation of approximately 7,880 feet.
Cabresto Creek	Located 1.6 miles upstream of the Carson National Forest boundary, at an elevation of approximately 7,640 feet.

1995 Benthic Invertebrate Data Collection

Study site locations for benthic invertebrate sampling by NMED in December 1995 (Woodward-Clyde 1996) on the Red River (Fig. 20) are as follows:

Upstream of Red River	Red River upstream of confluence with Bitter Creek (Site RRB-1).
Downstream of Red River	Downstream of the confluence with Pioneer Creek (Site RRB-3).
Near Elephant Rock Campground	Downstream of confluence with Hot-n-Tot Creek (Site RRB-5).
Downstream of Hansen Creek, upstream of Sulphur Gulch.	Red River between Hansen Creek and Sulphur Gulch (RRB-7).
Just downstream of Columbine Creek	Downstream of Columbine Creek (Site RRB-10A).
Upstream of Goathill Gulch	Downstream of Columbine Creek, upstream of Goathill Gulch (Site RRB-11).
Upstream of Capulin Canyon	Downstream of Goathill Gulch, upstream of Capulin Canyon (Site RRB-13).

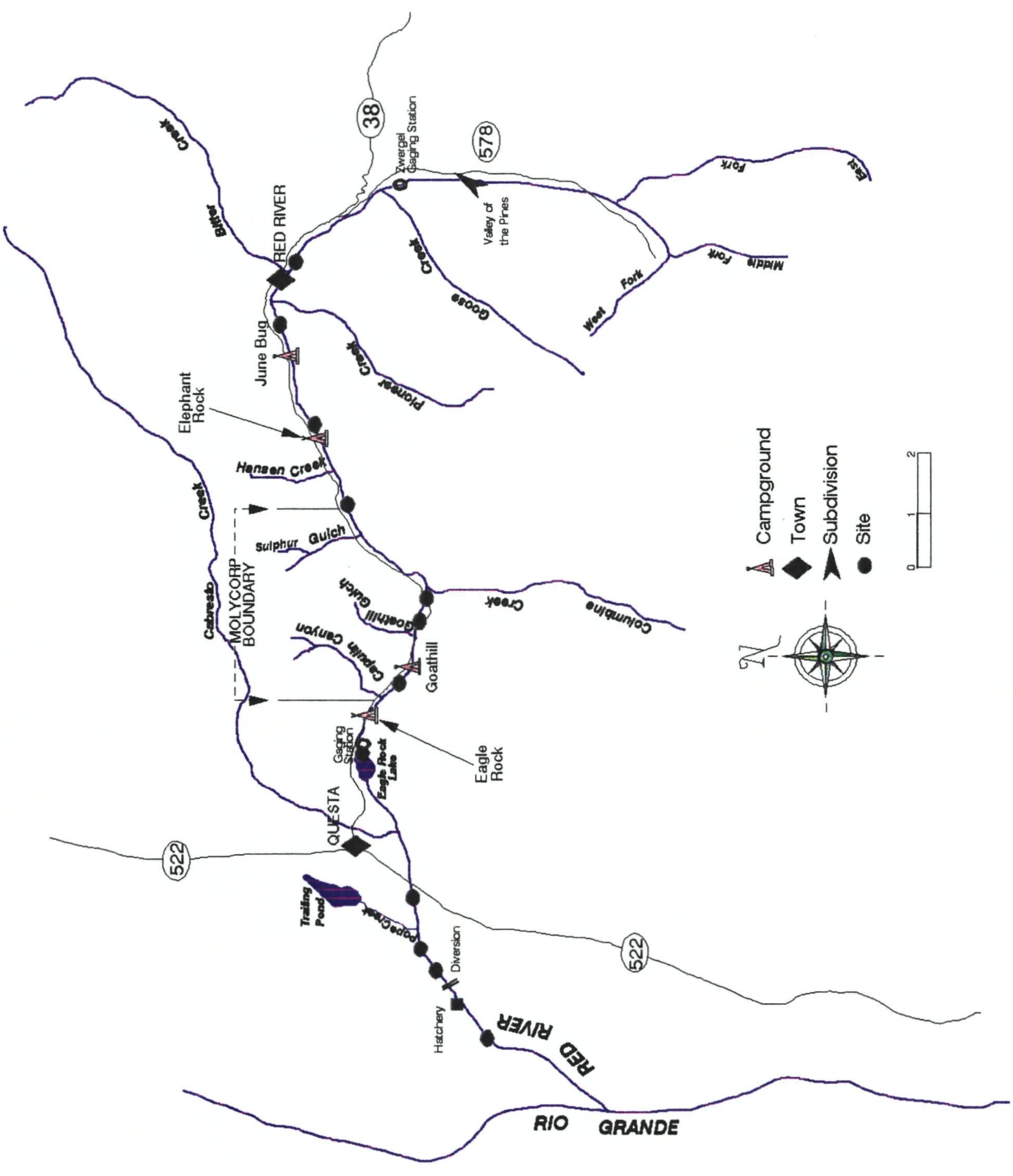


FIGURE 20: NMED December 1995 benthic invertebrate sampling sites (Woodward-Clyde 1996).

Near Questa Ranger Station	Downstream of USGS gaging station #0826500, near the Questa Ranger Station (Site RRB-16).
Downstream of Highway 522 Bridge	Just downstream of bridge, downstream of Cabresto Creek (Site LRB-1).
Downstream of Pope Creek	Downstream of tailings pond discharge outfall #002 (Site LRB-11A).
Upstream of hatchery diversion	At new spring water control boxes for fish hatchery (Site LRB-16).
Downstream of fish hatchery	Downstream of USGS gaging station #0266820, downstream of hatchery (Site LRB-21).

Historical Fish and Benthic Invertebrate Data Collection

The historical fish and benthic invertebrate data collection sites are described below. These sites have been grouped into the six reaches of the Red River in order to allow a more focused interpretation of the data.

Upstream of Red River

East Fork at Blue Lake Trail	3 miles upstream of confluence of east and west forks.
Just downstream of the Forks	Site just downstream of confluence of the east and west forks of the Red River.
2.0 mi. downstream of the Forks	2 miles downstream of the east and west forks of the Red River.
2.9 mi. downstream of the Forks	Located 2.9 miles downstream of confluence of the east and west forks of the Red River.
Downstream of Valley of the Pines	Upstream of the Zwergel Gaging Station, downstream of the Valley of the Pines subdivision.
Zwergel Gaging Station	Located 2.2 miles upstream of the Town of Red River.
Upstream of Bitter Creek	800 feet upstream of confluence with Bitter Creek and Red River.
Downstream of Bitter Creek	Just downstream of the confluence of Bitter Creek with Red River.

Red River to Hansen Creek

June Bug Campground	Located at June Bug Campground one mile west of the Town of Red River.
Elephant Rock Campground	At Elephant Rock Campground approximately 0.8 miles upstream from confluence of Hansen Creek and Red River.

Hansen Creek to Molycorp Boundary

Upstream of Molycorp property boundary.	0.5 mile stretch of Red River upstream of Molycorp property boundary; includes the Bobita Campground site sampled by NMDGF in 1995 and 1996.

Molycorp Boundary to Capulin Canyon

Upstream of Columbine Creek	Located just upstream of Columbine Creek, 6 miles east of Questa.
Downstream of Columbine Creek	500 feet downstream of confluence of Columbine Creek and Red River.
Upstream of Goathill Gulch	Approximately 0.8 miles feet upstream of confluence of Goathill Gulch and Red River.
Goathill Campground	Near confluence of Goathill Gulch and Red River approximately 1.8 miles upstream from USGS Gaging Station #08265000.

Capulin Canyon to Questa

Near Mouth of Bear Canyon	Located in the Red River at the mouth of Bear Canyon just downstream of Capulin Canyon; 1.2 miles upstream of head of Eagle Rock Lake.
Eagle Rock Campground	Located approximately 0.25 miles upstream from USGS Gaging Station #08265000.
Questa Ranger/Gaging Station	Site located near the USGS Gaging Station #08265000 near Questa Ranger Station.
Head of Eagle Rock Lake	Site located approximately 0.4 miles upstream from USGS Gaging Station #08265000, near Eagle Rock Lake Diversion.

Questa to Rio Grande

SH 522 Bridge (Formerly SH3)	Bridge where Highway 522 (formerly Highway 3) crosses Red River approximately 2.8 miles downstream from USGS Gaging Station #08265000.
Upstream of Pope Creek	Approximately 150 feet upstream of Pope Creek's confluence with Red River.
Upstream of hatchery diversion	A 0.5 mile stretch upstream of the Red River State Fish Hatchery, approximately 2 miles downstream of the bridge at SH 522.
Downstream of hatchery diversion	Just downstream of hatchery diversion and upstream of the Red River State Fish Hatchery.
Downstream of hatchery	Just downstream of the Red River State Fish Hatchery.
Between hatchery and El Aujae Campground	Several sampling sites in the 1.5 mile section of the Red River in the canyon downstream of the fish hatchery and upstream of the campground.
El Aujae Campground	Located approximately 1.5 miles downstream from the hatchery.
La Junta Point	La Junta point recreation site located about 3 miles downstream of the state hatchery.

METHODS

1997 Data Fish Collection

Fish populations were quantitatively sampled at ten sites during the week of March 31 through April 3, 1997. Sampling provided data on species composition, abundance, biomass, and the size structure of the fish community. The section of stream sampled at each site was chosen to be representative of the habitat present in that reach of stream, in terms of pool/riffle ratio, shading, bank stability, etc. Sites were of sufficient length to ensure a representative section of the available habitat features: 270 to 345 feet in length in the Red River, 128 feet in Cabresto Creek, and 208 feet in Columbine Creek.

Sampling was conducted by making three sampling passes through a representative section of stream using either bank or backpack electrofishing gear. Bank electrofishing equipment consisted of a 4,000 watt generator, a Coffelt voltage regulator (VVP-15), and two electrodes. Backpack electrofishing equipment consisted of a Coffelt Mark-10 CPS unit with one electrode. At all sites, sample sections were blocked with 50 ft seines (1¼ mesh) to reduce the potential for fish to enter or leave the study section during sampling.

Fish captured from each pass were kept separate to allow estimates of population density of each species using a maximum likelihood estimator and the "MicroFish" program developed by the U.S. Forest Service (Van Deventer and Platts 1983, 1986). All fish sampled were identified, counted, weighed, and released. This sampling provides species lists, estimates of abundance (#/mile, #/acre), and biomass (lbs/acre).

1995 Benthic Invertebrate Data Collection

Benthic invertebrates were quantitatively sampled at 12 sites by NMED personnel on December 20 and 21, 1995. Five replicate Hess samples were taken from riffle areas at each site. A full discussion of methods and the presentation of the data are found in Woodward-Clyde (1996).

Historical Fish and Benthic Invertebrate Data Collection

Fish

The historical fish data from the Red River were collected in most cases by the NMDGF. The majority of this sampling was done using a single pass electrofishing technique. Some of the more recent fish data were collected using a three pass electrofishing technique. In order to compare the data from the different studies, it was necessary to standardize the data to make comparisons appropriate. For all historical data collection (prior to 1997), fish collected on the first electrofishing pass are included in this report. For the data collected by Chadwick Ecological Consultants, Inc., in the spring of 1997, the data are presented based on the results of all three passes. However, comparisons to the historical data are made using only the first pass data collected in 1997, in order to be directly comparable.

In the NMDGF sampling summaries, it was often mentioned that they were working in turbid waters making fish observations difficult. A common pattern was to sample within one week after the river was stocked with trout. How the fish were identified or how length measurements were obtained were generally not mentioned in the reports; however, at least on some occasions, the collection crew would not actually collect the fish in a net, but would estimate the species and size of the fish as they floated by during electrofishing (R. Akroyd, NMDGF, personal communication). In some cases, the species of fish was not determined and was recorded as "Unknown."

Benthic Invertebrates

The early historical invertebrate surveys were conducted primarily by Dr. Robert Pennak, University of Colorado, Boulder. Later surveys were done by a variety of groups including NMED, US EPA, ENSR, and the New Mexico Surface Water Quality Bureau. A variety of sampling equipment was used, including Surber samplers, kick nets, delta frame dipnets and Hess samplers. Because there were different sampling methods, the data are presented in a variety of ways including number of taxa, density, biomass, and several different biotic indices.

In mountain streams, such as those near the Molycorp Molybdenum Mine, the presence of mayfly (Ephemeroptera), stonefly (Plecoptera), and caddisfly (Trichoptera) taxa (referred to as the EPT taxa) can be used as an indicator of water quality. These insect groups are considered to be sensitive to a wide range of pollutants (Weiderholm 1989, Plafkin *et al.* 1989, Klemm *et al.* 1990, Lenat and Penrose 1996, Wallace *et al.* 1996). Stress to aquatic systems can be evaluated by comparing the number of EPT taxa (expressed as the percent of EPT taxa relative to the total taxa) between unimpacted and potentially impacted sites. Impacted sites would be expected to have fewer EPT taxa (lower percent EPT taxa) compared to unimpacted sites.

Another useful biological indicator of water quality is the Shannon-Weaver Diversity Index (H'), which the EPA recommends as a measure of the effects of stress on invertebrate communities (Klemm *et al.* 1990). This index generally has values ranging from 0-4, with values from 2.5-4.0 indicative of a healthy invertebrate community (Klemm *et al.* 1990, Wilhm 1970).

RESULTS AND DISCUSSION

Water Quality Summary

With regard to the potential for harm to aquatic life, water quality data from 1988 through 1996 were reviewed, as provided by Molycorp (Vail Engineering 1993, 1995, 1997) and in reports by Smolka and Tague (1987, 1989), Smolka (1993), and Slifer (1996). This included data on flow (cfs), pH, and a number of constituents. From the perspective of aquatic life, it appears that three parameters are of potential concern: pH, zinc, and aluminum. Concentrations of these constituents were compared to applicable EPA water quality criteria (EPA 1986, 1987, 1988) and standards developed by the State of New Mexico.

Over the period from 1988 to 1996, pH throughout the Red River was generally in the range of 6.5 to 8.5 units. The pH did exhibit a general decrease from upstream to downstream, with the decrease beginning downstream of the hydrothermal scars on the Hot-n-Tot and Hansen Creek drainages. However, even though the pH decreased slightly, the values were predominately in the range that is considered safe for aquatic life (EPA 1986). Periods of lower pH values are associated with storm events eroding the thermal scars (Slifer 1996).

When considering the potential harm to aquatic biota from metals, it is important to consider the dissolved form. This is the form that is considered to most closely approximate the bioavailable (i.e. toxic) fraction of the metal (Bergman and Dorward-King 1997), and is the form preferred by the EPA with respect to water quality criteria (May 4, 1995, Federal Register 60:86 @ 22229-22237). This is also the form used for criteria developed by the State of New Mexico.

The zinc data that are available indicate a slight increase through the study area from less than 50 µg/L upstream of Red River to values around 70 to 100 µg/L downstream of the Questa Ranger Station (ENSR 1988, Vail Engineering 1993, 1995, 1996). To determine potential for harm, it is necessary to know the hardness since the zinc criteria are hardness based (EPA 1986. State of New Mexico, 20 NMAC 6.1, Sec. 3101, January 23, 1995, pp. 44-46, Standards Applicable to Attainable or Designated Uses). Smolka (1993) measured hardness monthly during 1992. Mean hardness during this time period increased from approximately 90 mg/L $CaCO_3$ near the Town of Red River to 176 mg/L at the Questa Ranger Station. Based on the most current New Mexico and EPA zinc criteria equation (EPA 1986, 1987. State of New Mexico, 20 NMAC 6.1, Sec. 3101, January 23, 1995, pp. 44-46, Standards Applicable to Attainable or Designated Uses) as modified for dissolved values (May 4, 1995, Federal Register 60:86 @ 22229-22237), these hardness values would result in chronic zinc criteria of 95 µg/L and 169 µg/L, respectively. The reported dissolved zinc values were well below these values in their respective reaches, indicating that neither chronic nor acute toxicity from dissolved zinc would be expected to occur in the Red River. Smolka and Tague (1989) also noted that during storm events, water quality in the Red River resulted in total metal concentrations that appeared to exceed water quality standards; however, when dissolved metals were considered, the criteria were not violated.

Aluminum has been shown to be toxic to aquatic biota a concentrations well less than 1 mg/L (Sparling and Lowe 1996), especially at pH values near 5.0 or lower. Fish are generally considered to be more sensitive than aquatic insects (Sparling and Lowe 1996, Heliövaara and Väisänen 1993). The toxicity of aluminum is reduced at pH values of 6.5 or higher. In the range of pH observed in the Red River, aluminum would be highly insoluble (Hem 1985). In addition, aluminum is prone to form colloidal hydroxides that can pass through a 0.45 µm pore filter (the filter used to determine dissolved metals). As such, the colloids will be reported as "dissolved" aluminum (Hem 1985), although they would not be bioavailable.

Concentrations of *total* aluminum increase from generally less than 1 mg/L upstream of the Town of Red River to values greater than 10 mg/L at the Questa Ranger Station (Vail Engineering 1993, 1995, 1997, Smolka and Tague 1987, 1989). Reported *dissolved* aluminum values are considerably lower, ranging from 48 µg/L (0.048 mg/L) to over 2,000 µg/L (2 mg/L) through the river (Fig. 21). With regard to potential for harm to aquatic life, EPA and the State of New Mexico have a criterion for dissolved aluminum, with 87 µg/L for the chronic criterion (EPA 1988, State of New Mexico, 20 NMAC 6.1, Sec. 3101, January 23, 1995, pp. 44-46, Standards Applicable to Attainable or Designated Uses). As is apparent from the data (Fig. 21), this chronic criterion is exceeded from the reaches upstream of the Molycorp property to the reach downstrem of Capulin Canyon. It is important to note that much of this reported "dissolved" aluminum may actually be in colloidal form and, thus, not bioavailable (i.e., not toxic). Nonetheless, these data would suggest a potential for toxicity to aquatic life from dissolved aluminum in the reaches of the river downstream of the Town of Red River to Questa (Fig. 21).

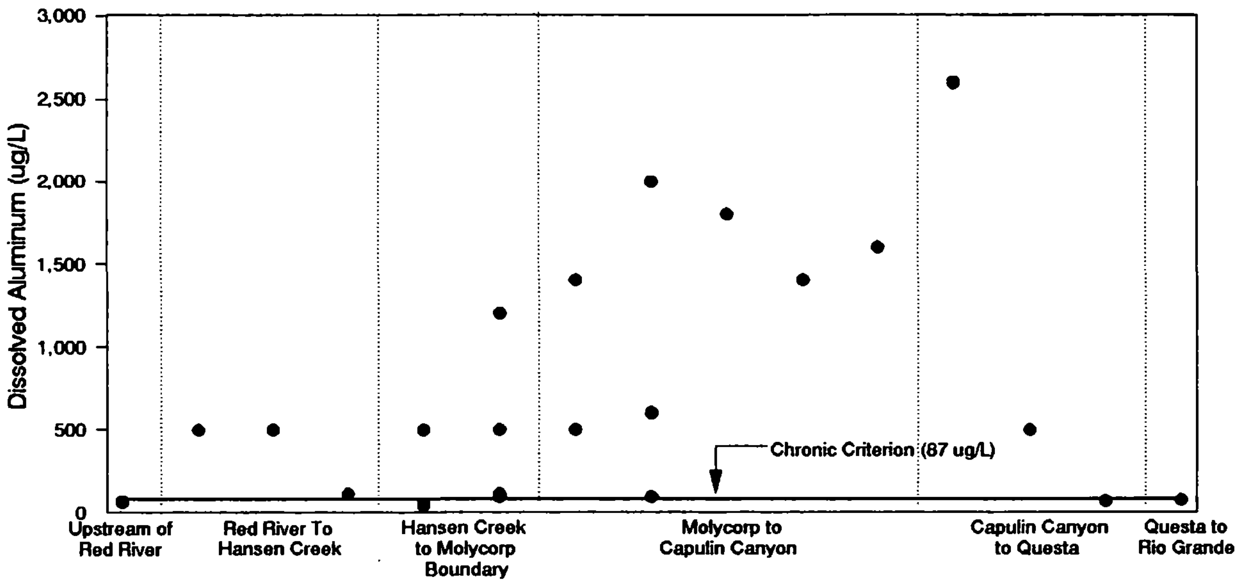


FIGURE 21: Dissolved aluminum concentrations in the six reaches of the Red River, New Mexico, (Smolka and Tague, 1988, South Pass Resources, Inc. 1995, Slifer 1996, Steffen Robertsen and Kirsten, Inc. 1995).

Present Fish Populations

A total of four different trout species were collected in the Red River and its tributaries during sampling on March 31 through April 3, 1997 (Table 1). Brown trout were the most common at eight of the ten sampled sites. Upstream of Red River, cutthroat trout were the most abundant species. In Cabresto Creek, a hybrid between rainbow and cutthroat trout were the most common.

Based on the size distribution of collected fish and past stocking records, it appears that cutthroat, brook, and brown trout are self-sustaining in the Red River and the two tributary streams. The size classes of fish collected indicate the presence of multiple size/age groups of these three species, indicating natural reproduction of these three species is occurring in the Red River and tributaries.

TABLE 1: Fish population parameters for collection sites on the Red River and tributaries. Data collected during March 31-April 3, 1997, by Chadwick Ecological Consultants, Inc. Data from three electrofishing passes (CUT = cutthroat trout, BRK = brook trout, RBT = rainbow trout, BRN = brown trout).

			Density		Biomass
Site, Date	Species	# Collected	#/Mile	#/Acre	Lbs./Acre
Red River					
Upstream of Town of Red River, 4/2/97	CUT	34	551	261	19.1
	BRK	19	291	138	5.9
	RBT	5	76	36	14.1
	BRN	5	199	94	8.4
	Total	63	1,117	529	47.5
June Bug Campground, 4/2/97	BRK	2	33	15	0.4
	RBT	8	133	60	14.5
	BRN	23	433	194	5.7
	HYBRID	10	200	90	8.1
	Total	43	799	359	28.7
Downstream of Elephant Rock Campground, upstream of Hansen Creek, 4/2/97	RBT	1	19	7	2.9
	BRN	28	570	220	16.5
	Total	29	589	227	19.4
Downstream of Hansen Creek, upstream of mill, 4/1/97	BRN	3	34	13	2.4
Downstream of mill, upstream of Columbine Creek, 4/1/97	RBT	1	19	9	3.3
	BRN	6	116	55	9.7
	Total	7	135	64	13.0
Goathill Campground, 4/1/97	BRN	13	243	107	6.8
Upstream of Questa Ranger Station, 4/1/97	NO FISH	--	--	--	--
Upstream of hatchery diversion, 3/31/97	RBT	20	395	164	43.1
	BRN	50	934	388	21.3
	Total	70	1,329	552	64.4
Tributaries					
Columbine Creek, 4/3/97	BRN	22	426	474	27.3
Cabresto Creek, 4/3/97	CUT	2	82	56	5.5
	BRK	4	165	111	5.1
	RBT	3	124	83	28.4
	HYBRID	18	784	528	35.4
	Total	27	1,155	778	74.4

All of the rainbow trout collected were larger than 7.5 inches, with most in the 8-11 inch size range. This is the size of fish commonly stocked in the river by NMDGFP over the last two decades, and are the target of the fisheries management efforts in the basin (R. Akroyd, NMDGF, personal communication). In the 1970's, it appears that small rainbow trout fry (several inches long) was stocked instead of the "catchable" size being stocked at present. The Town of Red River also apparently stocks rainbow trout, some of which are up to 20 inches in length. Rainbow trout are commonly stocked throughout the western United States. It has been our experience that stocked rainbow trout do not sustain populations through natural reproduction. Although a limited amount of natural reproduction may occur, this is uncommon. The rainbow trout levels in the Red River are probably maintained almost exclusively by stocking, and not natural reproduction. Within a few months of being stocked, most rainbow trout are no longer in the river, having died, migrated, or been caught by anglers. This is the typical pattern for stocked rainbow trout and is assumed throughout the remainder of this report when evaluating the available fish collection information for 1997 and for the historical data.

The hybrid fish collected at the site at June Bug Campground and in Cabresto Creek appeared to have characteristics of both cutthroat and rainbow trout. These two species are known to hybridize throughout the western U.S. (Behnke 1992). The small size of the collected hybrids suggests that these were the result of natural reproduction, not stocking.

Fish collection in the spring of 1997 was conducted prior to the stocking of rainbow trout at all sites except near the fish hatchery diversion, the most downstream site. Brown trout were the most common species of fish collected at most sites. Rainbow trout were not the most common species of trout collected at any of the ten sampling sites (Table 1). This directly contrasts with much of the historical data discussed in the remainder of this report (see Historical Fish Populations section). The reason for this is apparently that much of the historical data were collected during the stocking season for rainbow trout in the Red River. The significance of the 1997 data, prior to the stocking of rainbow trout, is that stocked rainbow trout are less of a confounding factor in interpreting the fish data and evaluating the suitability of the different reaches of the Red River for sustaining resident trout populations.

Winter, with low flows and cold temperatures, represents a difficult time for trout. The trout remaining in the Red River in spring allow a more direct interpretation of the ability of the reaches of the river to sustain trout through the most difficult season.

The fish collection data from the spring of 1997 indicates a very clear pattern (Fig. 22). Relative to the fish populations upstream of the Town of Red River, populations consistently decrease at each site within each reach to very low levels at the site below Hansen Creek and upstream of the Molycorp mill (Table 1). There is an approximately 30-40% decrease in fish populations parameters from the site upstream of the Town of Red River to the June Bug Campground Site (Table 1). The physical habitat of the Red River in this reach appears similar in suitability to the reach of the river upstream of the Town of Red River. This suggests that activities in or near the Town of Red River have a detrimental effect on trout populations. There is a further 25-40% decrease in trout population parameters between the June Bug and Elephant Rock Campground sites (Table 1). Again, the suitability of the physical habitat at these two sites appears to be similar. These two sites bracket the confluence of Hot-n-Tot Creek and a wastewater treatment plant outlet. Hot-n-Tot Creek drains runoff from a hydrothermal scar. These two factors appear to further impact the trout populations of the Red River.

Fish population parameters decrease an additional 90% between the Elephant Rock Campground site and the site downstream of Hansen Creek (Table 1). Hansen Creek also drains an extensive hydrothermal scar, forming a delta of fine sediment at its confluence with the Red River (Fig. 8). In addition, there is a spring just downstream of Hansen Creek that appears to provide a source of aluminum hydroxide precipitate into the Red River (Fig. 11).

Comparing the data from the site upstream of the Town of Red River to the site downstream of Hansen Creek, there is a 95% reduction in fish collected, a 97% reduction in the number of fish/mile, a 98% reduction in density (number of fish/acre), and a 95% reduction in biomass (lbs/acre). Therefore, the cumulative effect of the impacts to the Red River trout populations extending from the Town of Red River to a point upstream of the Molycorp property is a more than 95% reduction in fish populations.

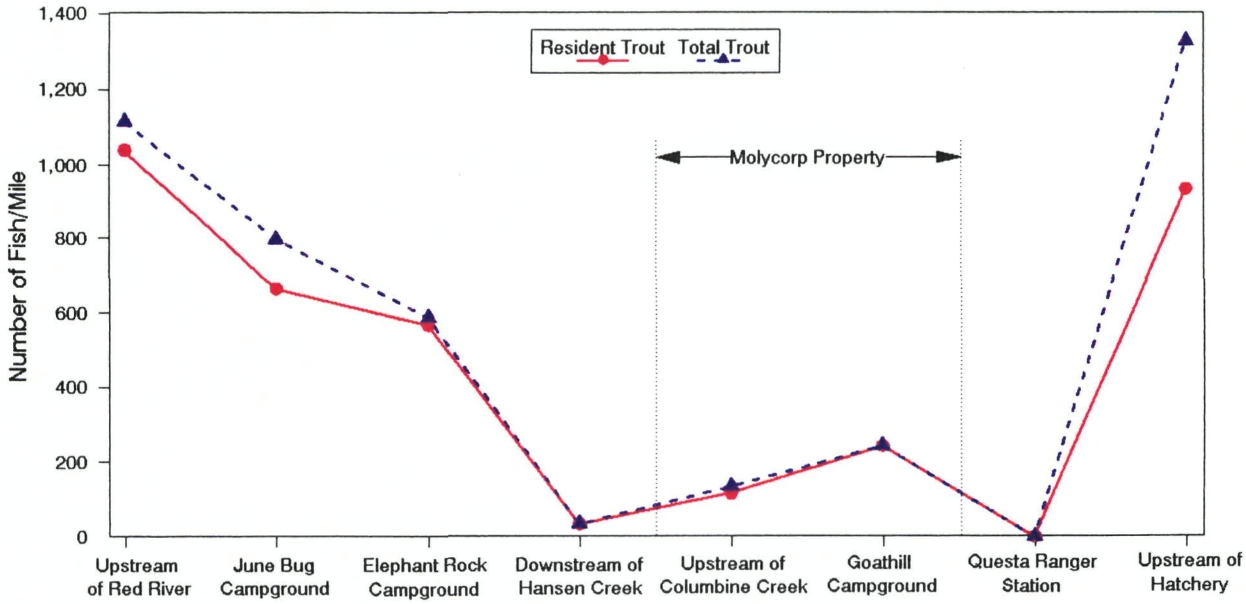


FIGURE 22: Trend in the number of fish per mile for data collected in spring, 1997. Data represent results of three electrofishing passes. Resident trout excludes stocked rainbow trout.

The single most important negative impact in this section appears to be the effects of Hansen Creek. Hansen Creek introduces substantial amounts of sediment, possibly with elevated levels of metals, to the Red River. The levels of sediment alone appear to render the section of the Red River downstream of the confluence unsuitable for maintaining all but a few trout. Water quality data indicate that during stable flow conditions, levels of zinc downstream of Hansen Creek do not appear to be toxic to fish, although aluminum may be. In addition, the possibility exists that short-term increased levels of metals, low pH, or sediment occurring during storm events may be toxic to fish. These factors would limit the suitability of the Red River to sustain trout in this reach of the river downstream of Hansen Creek.

Recent habitat ratings using the EPA's Rapid Bioassessment Protocol (RBP) method (Plafkin *et al.* 1989) were collected in 1995 and 1996 at four sites in the Red River (Akroyd 1996, 1997). The RBP method includes an estimation of substrate embeddedness. Embeddedness at the Bobita Campground sampling site (just downstream of Hansen Creek) was estimated to be 60% during both 1995 and 1996. In contrast, embeddedness at the site upstream of the Town of Red River was 25% and 35% in 1995 and 1996, respectively. This information indicates a substantial increase in the amount of sediment in the Red River downstream of Hansen Creek.

At the two collection sites adjacent to the Molycorp mine property, the site upstream of Columbine Creek, and the site at Goathill Campground, trout population parameters increase to a small extent, but remain low (Table 1, Fig. 22). Columbine Creek appears to improve conditions in the Red River to a small extent. The number of fish collected and fish density increase at the site downstream of Columbine Creek (the Goathill Campground Site) as compared to the site upstream of Columbine Creek. Columbine Creek itself supports a population of brown trout. These trout appear to be self-sustaining, based on the presence of multiple-size/age classes in this tributary to the Red River.

The short-term additions of water with high levels of sediment and metals, which may be occurring from Hansen Creek during storm runoff events, apparently do not occur in the reach of the river adjacent to the mine. Stormwater controls are apparently in place at the mine site to prevent this stormwater runoff (Slifer 1996). However, degraded water quality from Hanson Creek during storm events may still effect this reach of the Red River.

The site upstream of the Questa Ranger Station contained no fish when sampled in the spring of 1997 (Table 1). This site is downstream of the confluence with Capulin Canyon. This may be at least partially due to increased sedimentation in this reach of the river. Habitat data from Akroyd (1996, 1997) indicate a substrate embeddedness of 75% in this reach. This level of embeddedness would represent a substantial reduction in the suitability of the river to support fish.

Trout population parameters at the site upstream of the hatchery diversion are comparable to those at the site upstream of the Town of Red River (Table 1, Fig. 22). This is true even taking into account the rainbow trout recently stocked in this section. The recovery of the Red River to conditions that can sustain relatively high trout population levels may be due, in part, to the influence of Cabresto Creek. Cabresto Creek contained three species of trout and total trout biomass of Cabresto Creek was higher than at any other site sampled (Table 1).

Present Benthic Invertebrate Populations

The most recent benthic invertebrate data were collected in December 1995 by NMED personnel. The data were contained in a report by Woodward-Clyde Consultants (1996). This effort included replicate sampling at 12 sites along the Red River from upstream of the Town of Red River downstream to a point near the USGS gaging station (Station No. 0266820), downstream of the Red River State Fish Hatchery. This information is used to characterize the present status of the benthic invertebrate populations in the Red River.

The highest density and number of taxa occur at the sampling site upstream of the Town of Red River. Both the number of taxa and density decline at downstream sites (Table 2). This suggests impacts to the benthic invertebrate populations are beginning at the Town of Red River.

TABLE 2: Benthic invertebrate population parameters for collection sites on the Red River. Data collected during December 20-21, 1995, by NMED (Woodward Clyde 1996).

Site	#/m^2	# of Taxa	# EPT Taxa	EPT Taxa as % Total Taxa	Diversity Index
Upstream of Red River	10,121	48	23	48	2.80
Downstream of Red River	2,616	40	21	53	3.67
Near Elephant Rock Campground	4,030	34	18	53	3.40
Downstream of Hansen Creek, upstream of Sulphur Gulch	1,177	26	15	58	3.62
Just downstream of Columbine Creek	1,614	36	23	64	3.54
Upstream of Goathill Gulch	600	18	14	78	2.01
Upstream of Capulin Canyon	319	17	11	65	3.26
Near Questa Ranger Station	456	16	11	69	2.49
Downstream of Highway 522 Bridge	2,605	22	12	55	2.39
Downstream of Pope Creek	3,891	29	16	55	2.44
Upstream of hatchery diversion	4,449	34	14	41	2.08
Downstream of fish hatchery	6,012	45	23	51	2.42

At the site downstream of the Town of Red River, benthic invertebrate density decreased by 75% and was significantly lower (Analysis of Variance, ANOVA, $p = 0.0003$) than at the upstream site (Table 2, Fig. 23). This indicates impacts to benthic invertebrate populations are occurring near the Town of Red River. The number of taxa decreased by 17%, but the percent of EPT taxa was comparable at both sites. The impact in this reach of the river is probably a physical impact, such as a moderate increase in fine sediment input. Increased sediment at low levels has been shown to reduce the density of invertebrates in streams (Culp *et al.* 1986, Farnworth 1979, Rosenberg and Snow 1975, Gammon 1970) without necessarily resulting in substantial decreases in the number of taxa present.

Near the Elephant Rock Campground site, invertebrate density increased compared to the previous site, but was still significantly less than the site upstream of Red River (ANOVA, $p < 0.05$). This may reflect a slight enrichment effect of the wastewater treatment plant. While the percentage of EPT taxa and diversity index are comparable between the two sites, the total number of taxa decreased an additional 15% and the number of EPT taxa was 22% lower than the site upstream of Red River. This suggests that the impacts to the benthic invertebrate population seen at the site downstream of Red River are continuing at the Elephant Rock Campground.

Downstream of Hansen Creek, density of benthic invertebrates is reduced by over 70% and was significantly lower than the Elephant Rock Campground site (ANOVA, $p < 0.0001$). The number of taxa is reduced by an additional 23%, and the number of EPT taxa is reduced by an additional 17%. However, the percentage of EPT taxa and the diversity index are higher than at the Elephant Rock Campground Site. The continued presence of EPT taxa (although in lower numbers) combined with the significantly lower density would tend to indicate a physical impact; probably the negative impact of sediment input from Hansen Creek. Habitat ratings by Akroyd (1996, 1997) indicate an embeddedness of 60% in this reach of the river, which would support this position.

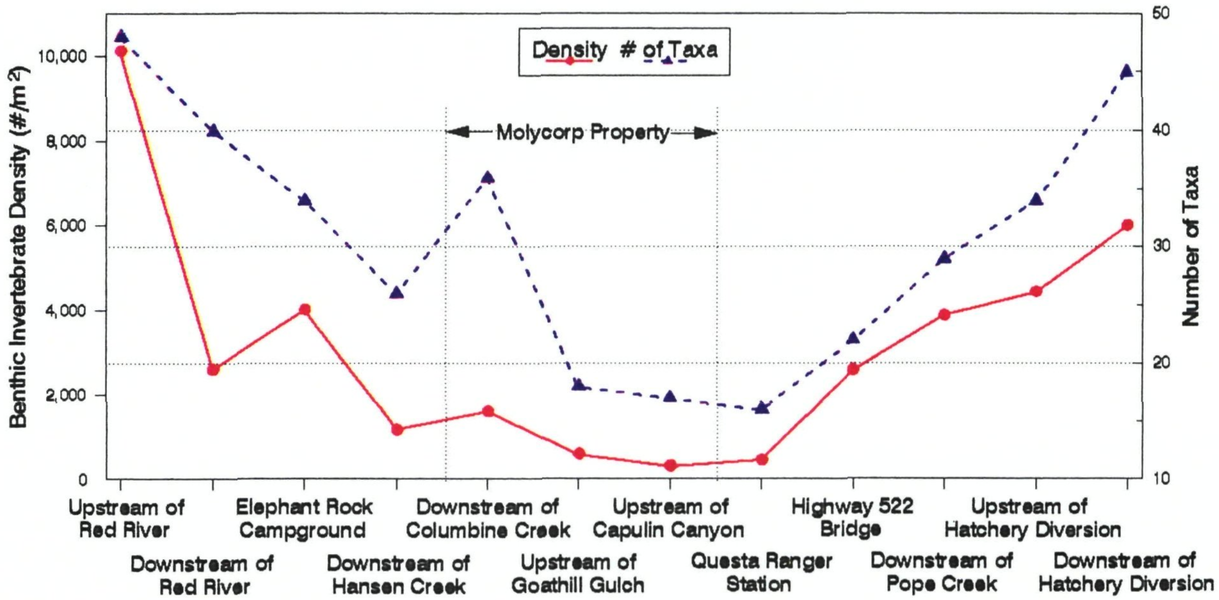


FIGURE 23: Trend in benthic invertebrate density and number of taxa for data collected in 1995.

Comparing the data from the site upstream of the Town of Red River to the site downstream of Hansen Creek, there is an 88% reduction in benthic invertebrate density, a 46% reduction in the total number of taxa, and a 35% reduction in the number of EPT taxa. These reductions are, in part, a result of fewer heptageniid mayflies, and capniid and nemourid stoneflies (Woodward-Clyde 1996). These organisms are often considered intolerant of stress (DeShon 1995, Klemm *et al.* 1990). Heptageniid mayflies have been identified as sensitive to input of metals, whereas stoneflies are often considered less sensitive to metals (Clements 1994). Both mayflies and stoneflies are sensitive to sediment input (Hynes 1970), and prefer coarse gravel/riffle substrates (Ward 1975, Hynes 1970). Therefore, the data do not clearly indicate the causes of the reductions observed.

At the next site downstream, the site just downstream of Columbine Creek, there are slight increases in the number of taxa and density. These increases are not significant; however, they suggest that Columbine Creek is having a positive effect on the Red River, possibly through the input of drifting benthic invertebrates (Hynes 1970, Allan 1995).

The next three downstream sites (upstream of Goathill Gulch, upstream of Capulin Canyon, and near the Questa Ranger Station) all indicate that impacts to benthic invertebrate populations are occurring (Table 2, Fig. 23). At all three of these sites, density is significantly lower (ANOVA, $p < 0.05$) than at the two sites bracketing Columbine Creek (the sites downstream of Hansen Creek and downstream of Columbine Creek). The low density and the approximately 50% reduction in number of taxa and EPT taxa, as compared to the site just downstream of Columbine Creek, could suggest either water quality and/or physical impacts to the population. The habitat ratings by Akroyd (1996, 1997) indicate an embeddedness of 75% in this reach of the river. This would indicate that sediment is having a substantial effect on invertebrate populations.

The next site downstream at the Highway 522 Bridge is also downstream of Cabresto Creek. As compared to the Questa Ranger Station site, the Highway 522 Bridge site has significantly higher density (ANOVA, $p = 0.006$). The number of taxa also increased substantially, although EPT taxa did not exhibit a significant increase. Much of the increase in density can be attributed to higher numbers of the sensitive mayfly group (Woodward-Clyde 1996). The population parameters indicate a significant improvement in the suitability of the Red River to support invertebrates downstream of Cabresto Creek.

The three sites downstream of Questa (downstream of Pope Creek, upstream of hatchery diversion, downstream of fish hatchery) shows an increasing trend in the number of taxa and density (Table 2, Fig. 23). These parameters indicate that the suitability of the Red River to support benthic invertebrates is becoming more similar to that found upstream of the Town of Red River, exhibiting the same overall trend seen in the trout populations (Fig. 22).

Historical Fish Populations

<u>Upstream of Red River</u>

The reach of the Red River upstream of the Town of Red River has historically contained the most diverse fish populations in the river. Over the period from 1960 to the present, cutthroat, brook, brown, and rainbow trout have been collected. In most cases, rainbow trout were the most abundant species present

(Appendix A, Table A1). Rainbow trout populations appear to be sustained by stocking. Cutthroat, brook, and brown trout populations are apparently sustained by natural reproduction.

The baseline data in this reach of the Red River, based on the results of sampling in 1960, indicate that cutthroat and brook trout were present. The abundance of fish was 352 fish per mile in 1960 (Table 3).

TABLE 3: Historical fish collection data for the reach of Red River upstream of the Town of Red River. First pass data only.

Site, Date	Total # Collected	Total #/Mile	% RBT
East Fork at Blue Lake Trail			
June/Aug. 1960	20	352	0
Just downstream of the Forks			
Nov. 1975	35	700	91
May 1977	112	1,120	96
July 1978	96	960	99
Sept. 1978	24	480	100
2.0 mi. downstream of the Forks			
Nov. 1975	27	540	59
May 1977	86	860	94
July 1978	56	560	96
Sept. 1978	13	260	100
2.9 mi. downstream of the Forks			
Nov. 1975	37	740	62
May 1977	148	1,480	95
July 1977	66	660	94
Downstream of Valley of the Pines			
Aug. 1995	45	724	20
Zwergel Gaging Station			
May 1977	51	510	75
July 1978	73	730	55
Sept. 1978	30	600	20
Sept. 1980	28	493	18
Sept. 1988	23	371	70
Aug. 1996	95	1,529	6

During the 1970's and the 1980's, the abundance of fish has varied widely, from 371 fish/mile to over 1,500 fish/mile. Stocked rainbow trout comprised the majority of this abundance in most years at most sites (Table 3). During the early to mid-1970's, the rainbow trout were apparently stocked as fry, fish of several inches in size. The fish collection data for these sites (Appendix A, Table A1) indicates that the conditions in this reach of the Red River were suitable to allow some of these fish to grow to average lengths of up to 8-10 inches.

The fish collection data indicate that water quality and habitat conditions during baseline conditions (1960 data), at present (1997 data), and in the intervening years were suitable to sustain healthy trout populations upstream of the Town of Red River. Without the stocking of rainbow trout, populations of cutthroat, brook, and brown trout would continue to sustain healthy populations.

Red River to Hansen Creek

Rainbow and brown trout were the most common species of trout in the section of the Red River downstream of the Town of Red River and upstream of Hansen Creek (Appendix A, Table A1). Rainbow trout appear to have been maintained by stocking; brown trout were probably self-sustaining through natural reproduction or immigration. Cutthroat and brook trout were occasionally present, but in low numbers, and probably represent fish that had migrated downstream from the reach upstream of Red River. One white sucker was present in 1975.

The abundance of fish varies considerably in this reach of the Red River (Table 4). The baseline (1960) abundance was a total of 632 trout/mile in the upper portion of this reach. However, two-thirds of these fish were stocked rainbow trout. During the 1970's and the 1980's, the majority of the fish were stocked rainbow trout, with brown trout maintaining abundance of up to 150 fish/mile. In some years, abundance of both brown and rainbow trout was low, less than a few hundred fish/mile. In 1983, at the Elephant Rock Campground site, no fish were found. This is in contrast to the trout populations in the reach upstream of the Town of Red River, which usually exhibited higher trout densities than those found in the reach of the river downstream of the Town of Red River. As previously noted, the suitability of the physical habitat to support trout in these two reaches of the Red River appears to be similar.

TABLE 4: Historical fish collection data for the reach of the Red River from the Town of Red River downstream to Hansen Creek. First pass data only.

Site, Date	Total # Collected	Total #/Mile	% RBT
June Bug Campground			
Oct. 1960	20	632	65
Nov. 1975	18	180	11
May 1977	53	530	89
July 1978	96	960	76
Sept. 1980	30	1,072	97
Sept. 1983	14	280	71
Elephant Rock Campground			
Nov. 1975	5	50	80
May 1977	23	230	96
July 1978	20	200	100
Sept. 1983	0	0	0
Sept. 1988	6	97	16

The relatively low trout density in this reach of the river, as compared to the reach of the river upstream of the Town of Red River, combined with the apparent continued decrease from June Bug to Elephant Rock Campgrounds, suggest that there have been impacts to the trout fishery in this section of the river over time. These impacts probably include activities in the Town of Red River, erosion from disturbed areas (i.e. the thermal scar on Hot-n-Tot Creek), septic and underground storage tank leaks, development, etc. (Chadwick Ecological Consultants, Inc., personal obervation, Slifer 1996).

The fish collection data suggest that the reach of the Red River from the Town of Red River downstream to Hansen Creek can support trout. However, the suitability of this reach of the river is lower than that of the reach upstream of the Town of Red River.

Hansen Creek to Molycorp Boundary

The reach of the Red River downstream of the confluence with Hansen Creek contains very few trout (Table 5). Nearly all of the fish collected in this reach were rainbow trout, with few brown trout collected (Appendix A, Table A1). As discussed earlier, the rainbow trout were probably maintained by stocking.

The brown trout were probably maintained by immigration downstream from more abundant trout populations in upstream sections of the river. Baseline conditions were probably similar, although there was apparently no sampling site in this reach of the river in 1960, or prior to the initiation of open pit mining.

TABLE 5: Historical fish collection data for the reach of the Red River from Hansen Creek downstream to the Molycorp property boundary. First pass data only.

Site, Date	Total # Collected	Total #/Mile	% RBT
Upstream of Molycorp property boundary			
Nov. 1975	2	40	100
July 1978	2	20	100
Sept. 1980	4	143	100
Aug. 1995	10	162	50
Aug. 1996	7	113	29

The input of sediment from Hansen Creek appears to be the major impact to the trout fishery in the section of the Red River downstream from Hansen Creek, although increased concentrations of dissolved aluminum may contribute. Hansen Creek drains a hydrothermal scar that is apparently the source of the sediment. Increased sediment can induce stress in trout in a number of ways, leading to a reduced suitability of the reach of river to sustain fish (Johnson *et al.* 1987, McLeay *et al.* 1987, Farnworth *et al.* 1979, Rosenberg and Snow 1975, Wallen 1951). In addition, Hansen Creek and the spring just downstream of Hansen Creek periodically input increased levels of metals, TSS, and metal precipitate, as well as low pH levels following storm events.

Molycorp Boundary to Capulin Canyon

Rainbow trout comprise the majority of the fish collected in the reach of the Red River adjacent to the Molycorp mine property. Cutthroat and brown trout were also occasionally present at the sites in this reach (Appendix A, Table A1). The rainbow trout were probably maintained by stocking; the brown trout have probably been maintained by immigration from upstream populations or from the population in Columbine Creek. The few cutthroat trout present were probably migrants from upstream populations, as cutthroat trout are generally inhabitants of smaller, higher elevation stream segments.

Abundance of trout was generally low and comprised predominantly of stocked rainbow trout (Table 6). The single site sampled in this reach of river in 1960 (upstream of Columbine Creek) indicates that the baseline conditions included 281 trout/mile, with approximately two-thirds of this amount being stocked rainbow trout. This abundance level is somewhat higher than that found in the reach of the Red River upstream of the Molycorp boundary in the 1970's (Table 5), although no site was sampled in that reach during 1960.

TABLE 6: Historical fish collection data for the reach of the Red River from the Molycorp property boundary downstream to Capulin Canyon. First pass data only.

Site, Date	Total # Collected	Total #/Mile	% RBT
Upstream of Columbine Creek			
Oct. 1960	16	281	69
Downstream of Columbine Creek			
Nov. 1975	12	240	42
Sept. 1980	11	195	100
Upstream of Goathill Gulch			
May 1977	0	0	0
Goathill Campground			
Nov. 1975	11	220	55
April 1977	74	740	93
July 1978	12	120	92
Sept. 1980	12	430	100
Sept. 1983	2	40	100

There is some evidence that the input of water from Columbine Creek has a positive influence on trout populations or may provide a source of colonizing trout. At the sites downstream of the confluence with Columbine Creek, abundance was sometimes higher than at the 1960 site upstream of Columbine Creek (Table 6), or in the reach of the river upstream of the Molycorp property boundary (Table 5). However, this positive influence is slight. Throughout the length of this reach of river, there appears to be little increase in trout abundance from the low levels found in the reach between Hansen Creek and the Molycorp boundary.

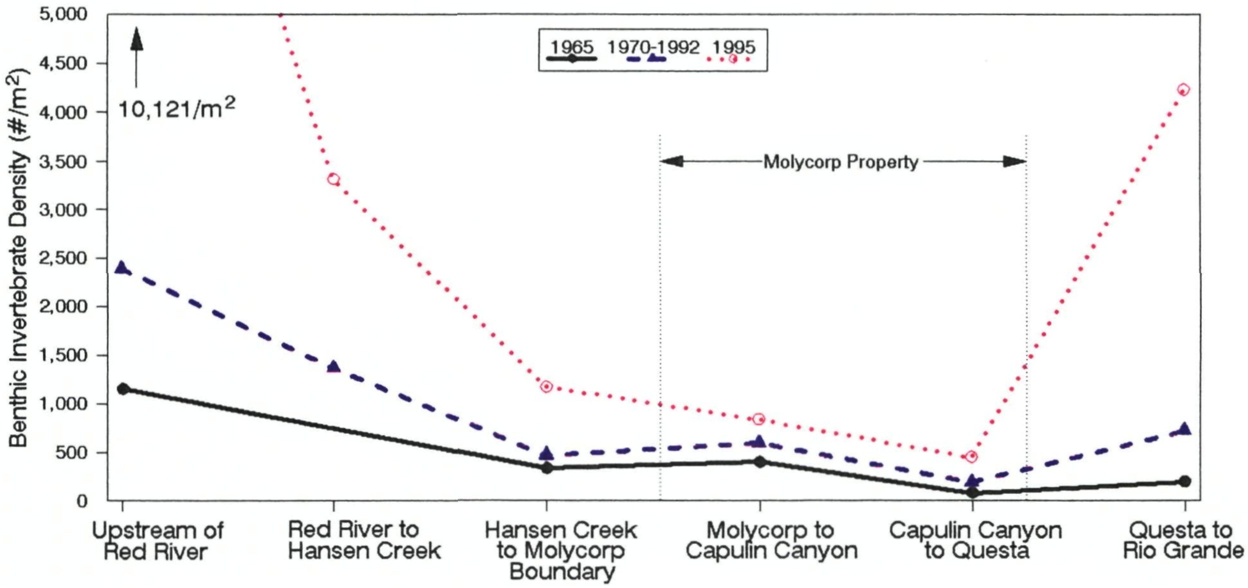


FIGURE 25: Longitudinal trends in benthic invertebrate density (no./m^2) for baseline conditions (1965 data), open pit mine operation (1970-1992), and the present (1995).

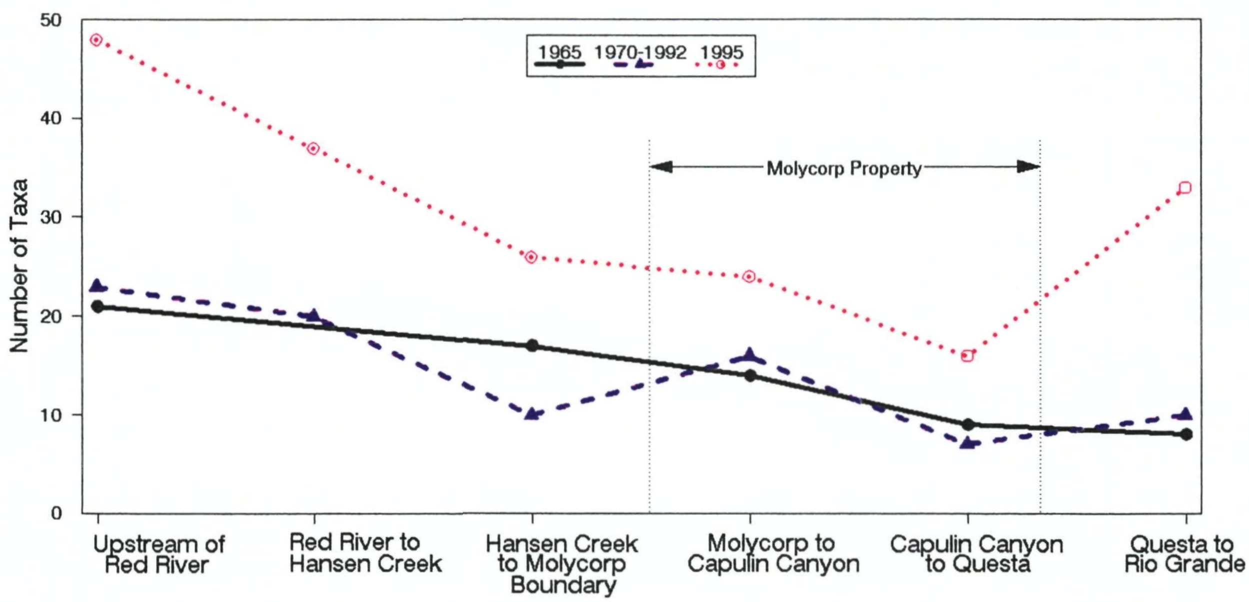


FIGURE 26: Longitudinal trends in the number of benthic invertebrate taxa for baseline conditions (1965 data), open pit mine operation (1970-1992 data), and the present (1995 data).

CONCLUSIONS

Fish data were collected during three separate periods. Baseline data were collected in 1960; recent data were collected in 1997; data during the operation of the Questa Molybdenum Mine were collected during 1974-1988. The three sets of data indicate a similar pattern of fish density along the length of the Red River.

All three data sets indicate that negative impacts to fish populations occur in the reach downstream of the Town of Red River. These impacts appear to be the result of increased sedimentation of the river. All three data sets also indicate that a more substantial impact to fish populations occurs downstream of Hansen Creek. Apparently, this is due to increased sedimentation of the Red River from the input of sediment from Hansen Creek, although periodic inputs of elevated metals and reduced pH from the thermal scars during storm events may contribute to the decrease. This trend was established in 1960, prior to the initiation of open pit mining at the Questa Mine.

The baseline data indicate that the lowest fish population levels in the Red River occurred in 1960 at the site adjacent to the future open-pit mine (the site sampled upstream of Columbine Creek). The data from 1974-1988 and 1997 also indicate low fish population levels in this reach of the river. However, these two data sets exhibited lower fish density at the sites just downstream of Hansen Creek, upstream of the mine.

The three data sets also indicate increasing fish densities at sites downstream of Questa. This is apparently due to improvements in the sediment levels, and perhaps water quality at sites in this reach of the river.

The similarity in the longitudinal trend in fish density between the three data collection periods (1960, 1974-1988, 1997) indicates that the relative suitabilities of the distinct reaches of the Red River to sustain fish populations has not changed substantially over this period. This trend is apparently independent of open pit mining activities, including the creation of the waste rock piles at the Questa Molybdenum Mine.

Comparisons between baseline fish densities and present conditions indicate that, at all corresponding sampling sites between 1960 and 1997, there are higher densities of resident trout (excluding stocked rainbow trout) at present than during baseline conditions. Although sampling methods between the two periods were different, this indicates that the suitability of the Red River to sustain trout likely has improved over this period.

The present trend in trout density (1997 data) indicates impacts to the fishery occur near the Town of Red River. A much more substantial impact occurs downstream of Hansen Creek, upstream of the Questa Mine. In this reach of the river, fish population parameters have decreased by over 95% as compared to the reach upstream of the Town of Red River. Downstream of Capulin Canyon, the trout density is reduced to zero, apparently as a result of the impact of sediment on the fishery. The suitability of the Red River to support trout downstream of Questa improves to levels comparable to that found upstream of Red River.

Benthic invertebrate data collection parallels that of fish data collection, with baseline data collected in 1965, recent data collected in 1995, and data collected during the operation of the open pit mine during the years of 1970-1992. The three sets of benthic invertebrate data indicate a similar pattern of invertebrate population parameters along the length of the Red River.

All three data sets indicate a substantial reduction in benthic invertebrate density and number of taxa in the reach from the Town of Red River to the reach downstream of Hansen Creek. Apparently this is due to the increased sedimentation of this reach of the river, although periodic input of metals and lower pH during storm flows may contribute to the trend.. This trend was established in 1965, prior to the initiation of open pit mining.

The baseline data indicate lowest benthic invertebrate density occurred in the reaches of the Red River from Hansen Creek downstream to Questa. This pattern is also evident from data collected in 1970-1992 and from data collected in 1995. All three data sets indicate increasing density at sites downstream of Questa. This is apparently due to improvements in sediment levels and/or water quality at the sites in this reach of the river. The number of taxa follows a similar longitudinal trend, with decreasing numbers of taxa in reaches downstream of the Town of Red River. However, in contrast to the density data, the number of taxa continues to decline for all three data sets down to lowest levels in the reach downstream of Capulin Canyon.

The similarity in the longitudinal trend in benthic invertebrate population parameters for all three data collection periods (1965, 1970-1992, 1995) indicates that the relative suitabilities of the reaches of the Red River to support invertebrates has not changed substantially over this period. The reaches of the Red River from Hansen Creek downstream to Questa have supported reduced populations of benthic invertebrates in the past, and at present. This trend is independent of open pit mining activities at the Questa Molybdenum Mine.

Present invertebrate population levels are higher than for baseline conditions. Although sampling methods between the two periods were different, this suggests that there may have been improvements in the suitability of the Red River to support invertebrates over the period from 1965 to 1995.

The present trend in benthic invertebrate populations indicates impacts occur downstream of the Town of Red River. As was the case with fish populations, a much more substantial impact occurs downstream of Hansen Creek, but upstream of the Questa Mine. Through the reaches of the river adjacent to the mine, and downstream of Capulin Canyon, there are further decreases in invertebrate population levels. Downstream of Questa, the populations improved substantially.

The trends for both fish and benthic invertebrates indicate that the cumulative impacts of sediment from a number of sources, and possibly decreased water quality, substantially decrease the suitability of the Red River to sustain aquatic biota in the reaches upstream of the Molycorp Questa Mine. This pattern was evident during both baseline and present conditions. In the reaches of the river adjacent to the mine and downstream of Capulin Canyon, the suitability of the river to sustain aquatic biota does not improve. This pattern was established prior to open pit mining during baseline conditions and continues to the present. The open pit mine and waste rock piles do not appear to have measurably impacted the suitability of the Red River to support aquatic biota.

LITERATURE CITED

Akroyd, R.F., Jr. 1984. Electrofishing Survey of Red River. New Mexico Department of Game and Fish Memo to Mike Hatch.

Akroyd, R.F., Jr. 1985. Electroshocking Lower Red River. New Mexico Department of Game and Fish Memo to Mike Hatch.

Akroyd, R.F., Jr. 1987a. 1986 Electroshocking Survey of the Lower Red River Revised to Show Correction in Estimated No./Mile. New Mexico Department of Game and Fish Memo to Mike Hatch.

Akroyd, R.F., Jr. 1987b. 1987 Survey of Red River. New Mexico Department of Game and Fish Memo to Mike Hatch.

Akroyd, R.F., Jr. 1988. 1988 Surveys of Red River. New Mexico Department of Game and Fish Memo to Michael Hatch.

Akroyd, R.F., Jr. 1996. Investigations of Trout Management Strategies. New Mexico Department of Game and Fish Performance Report, Grant F-60, Project 13.

Akroyd, R.F., Jr. 1997. Investigations of Trout Management Strategies. New Mexico Department of Game and Fish Performance Report, Grant F-60, Project 13.

Allan, J.D. 1995. *Stream Ecology: Structure and Function of Running Waters*. Chapman and Hall, New York, New York.

Atchison, G.J., M.G. Henry, and M.B. Sandheinrich. 1987. Effects of metals on fish behavior: a review. *Environmental Biology of Fishes* 18:11-25.

Behnke, R.J. 1992. Native Trout of Western North America. American Fisheries Society Monograph 6. AFS. Bethesda, MD. 275 pp.

Bergman, H.L., and E.J. Dorward-King (eds.). 1997. *Reassessment of Metals Criteria for Aquatic Life Protection*. SETAC Technical Publication Series, SETA Press, Pensacola, Florida.

Bode, R.W., and M.A. Novak. 1995. Development and application of biological impairment criteria for rivers and streams in New York state. pp 97-107. IN: Davis, W.S. and T.P. Simon (eds.). *Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making.* Lewis Publishers, Boca Raton, Florida.

Chadwick, J.W., and S.P. Canton. 1984. Inadequacy of diversity indices in discerning metal mine drainage effects on a stream invertebrate community. *Water, Air & Soil Pollution* 22:217-223.

Chadwick, J.W., S.P. Canton, and R.L. Dent. 1986. Recovery of benthic invertebrate communities in Silver Bow Creek, Montana, following improved metal mine wastewater treatment. *Water, Air & Soil Pollution* 28:427-438.

Chutter, F.M. 1969. The effects of silt and sand on the invertebrate fauna of streams and rivers. *Hydrobiologia* 34:57-76.

Clements, W.H. 1994. Benthic invertebrate community responses to heavy metals in the Upper Arkansas River Basin, Colorado. *Journal of the North American Benthological Society* 13:30-44.

Culp, J.M., F.J. Wrona, and R.W. Davies. 1986. Responses of stream benthos and drift to fine sediment deposition versus transport. Canadian Journal Zoology. 64:1345-1351.

DeShon, J.E. 1995. Development and application of the invertebrate community index (ICI). pp. 257-243. IN: Davis, W.S. and T.P. Simon (eds). *Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making*. Lewis Publishers, Boca Raton, Florida.

ENSR. 1988. Molycorp, Inc. Questa, New Mexico. Aquatic ecosystem survey of the Red River, New Mexico. Report prepared for Molycorp, Inc.

Farnworth, E.G., M.C. Nichols, C.N. Vann, L.G. Wolfson, R.W. Bosserman, P.R. Hendrix, F.B. Gulley, and J.L. Cooley. 1979. Impacts pf sediment and nutrients on biota in surface waters of the United States. U.S. EPA, Environmental Research Laboratory. EPA 600/3-79-105. 331 pp.

Gammon, J.R. 1970. The effect of inorganic sediment on stream biota. U.S. EPA, Water Pollution Control Research Series. 18050 DWC 12/70. 141 pp.

Giattina, J.D., R.R. Garton, and D.G. Stevens. 1982. Avoidance of copper and nickel by rainbow trout as monitored by a computer-based data acquisition system. *Transactions of the American Fisheries Society* 111:491-504.

Heliövaara, K., and R. Väisänen. 1993. *Insects and Pollution*. CRC Press, Boca Raton, Florida.

Hem, John D. 1985. U.S. Geological Survey Water-Supply Paper 2254: Study and Interpretation of the Chemical Characteristics of Natural Water. 3rd edition. U.S. Department of the Interior.

Hynes, H.B.N. 1970. *The Ecology of Running Waters*. University Toronto Press, Toronto, Canada.

Jacobi, G.Z. and L.R. Smolka. 1984. Intensive Survey of the Red River in the Vicinity of the Red River and Questa Wastewater Treatment Facilities and the Molycorp Complex, Taos County, New Mexico, January 25-27, 1984.

Johnson, R.A., J.H. Chipman, R.M. Lipchak. 1987. Recycling to reduce sediment discharge in placer mining operations. Journal Water Pollution Control Federation. 59(5):274-283.

Klemm, D.J., P.A. Lewis, F. Fulk, and J.M. Lazorchak. 1990. *Macroinvertebrate field and laboratory methods for evaluating the biological integrity of surface waters*. U.S. Environmental Protection Agency. EPA/600/4-90/303.

Lenat, D.R., and D.L. Penrose. 1996. History of EPT taxa richness metric. *Bulletin of the North American Benthological Society*. 13:305-307.

McLeay, D.J., I.K. Birtwell, G.F. Hartman, and G.L. Ennis. 1987. Responses of arctic grayling (*Thymallus arcticus*) to acute and prolonged exposure to Yukon placer mining sediment. Canadian Journal of Fisheries and Aquatic Sciences. 44(3):658-673.

Melancon, S.M.S., L.S. Blakely, and J.J. Janik. 1982. Site Specific Water Quality Assessment: Red River, New Mexico. U.S. Environmental Protection Agency, EPA 600/x-82-025, Las Vegas, Nevada.

Nelson, S.M. and R.A. Roline. 1993. Selection of the mayfly *Rhithrogena hageni* as an indicator of metal pollution in the upper Arkansas River. *Journal of Freshwater Ecology* 8:111-119.

New Mexico Department of Game and Fish. 1960. Stream Survey Forms.

Pacific, R.D. 1979. Fishery Resources in and Fisherman Use of the Lower Red River, Taos County, New Mexico (BLM). U.S. Fish and Wildlife Service Memo to Herb Garn, U.S. Bureau of Land Management.

Parish, B. 1975a. Red River Electrofishing. New Mexico Department of Game and Fish Memo to Bob Patterson.

Parish, B. 1975b. Red River Minimum Flows. New Mexico Department of Game and Fish Memo to Warren McNall.

Parish, B. 1976a. Electrofishing Results of Red River. New Mexico Department of Game and Fish Memo to File.

Parish, B. 1976b. Electrofishing Lower Red River. New Mexico Department of Game and Fish Memo to File.

Parish, B. 1977a. Electrofishing the Red River after Molycorp Spill. New Mexico Department of Game and Fish Memo to Jim Yarbrough.

Parish, B. 1977b. C-15 Electrofishing Red River. New Mexico Department of Game and Fish Memo to Jim Yarbrough.

Parish, B. 1978a. C-15 Electrofishing the Red River. New Mexico Department of Game and Fish Memo to Bob Patterson.

Parish, B. 1978b. Electrofishing the Red River. New Mexico Department of Game and Fish Memo to Bob Patterson.

Parish, B. 1979. Electrofishing Results in the Red River. New Mexico Department of Game and Fish Letter to Herb Garn.

Patterson, B. 1974. Electrofishing Red River below Hatchery. New Mexico Department of Game and Fish Memo to R.L. Brashears.

Patterson, B. 1983. Electrofishing Red River between Elephant Rock and Red River. New Mexico Department of Game and Fish Memo to Dick McCleskey.

Patterson, B. 1984. Electrofishing Red River below Hatchery. New Mexico Department of Game and Fish Memo to Dick McCleskey.

Pennak, R.W. 1972. Limnological Conditions in the Red River, New Mexico, during the Open Season of 1971, with Special Reference to the Effects of a Large Settling Pond Tributary. Report prepared by the Rocky Mountain Center on Environment.

Pennak, R.W. 1976. Aquatic Ecosystems of Red River, New Mexico, in October 1976; A Comparison with Conditions in October 1971. Report prepared by Thorne Ecological Institute.

Pennak, R.W. 1977a. Red River, New Mexico, Aquatic Ecosystems: March 1977 as Compared with 1971 and 1976. Report submitted to the Molybdenum Corporation of America.

Pennak, R.W. 1977b. Red River, New Mexico, Aquatic Ecosystems: October 1977 as Compared with October 1971 and October 1976. Report submitted to the Molybdenum Corporation of America.

Pennak, R.W. 1978. Summary Comments on Aquatic Conditions in the Red River, New Mexico, in 1978 as Compared to 1971-1977. Report prepared for the Molybdenum Corporation of America.

Pennak, R.W. 1979. Ecosystem Conditions in the Red River in the Late Summer of 1979: Effects of Abnormally High Runoff. Report prepared for the Molybdenum Corporation of America.

Pennak, R.W. 1981. Aquatic ecosystem in the Red River, New Mexico, in July 1981. Report prepared for the Molybdenum Corporation of America.

Pennak, R.W. 1983. Aquatic Ecosystem Conditions in the Red River, New Mexico, in October 1982. Report prepared for Molycorp, Inc.

Pennak, R.W. 1984. Aquatic Ecosystem Conditions in the Red River, New Mexico; October 1983.

Plafkin, J.L., M.T. Barbour, K.D. Porter, S.K. Gross and R.M. Hughes. 1989. Rapid Bioassessment Protocols for Use in Streams and Rivers. U.S. Environmental Protection Agency, EPA/444/4-89-001.

Rosenberg, D.M. and N.B. Snow. 1975. Ecological studies of aquatic organisms in the Mackenzie and Porcupine River drainages in relation to sedimentation. Department of the Environment, Fisheries and Marine Service Research and Development Directorate. Technical Report No. 547. 86 pp.

Rosenberg, D.M. and V.H. Resh (eds.). 1993. *Freshwater Biomonitoring and Benthic Macroinvertebrates.* Chapman and Hall, New York, New York.

Schilling, J. 1990. A history of the Questa Molybdenum (Moly) Mines, Taos County, New Mexico. New Mexico Geological Society Guidebook, 41st Field Conference. pp. 381-386.

Slifer, D. 1996. Red River Ground Water Investigation. New Mexico Environment Department. Surface Water Quality Bureau. Final report submitted to U.S. EPA Region VI.

Smolka, L.R. 1993. Special Water Quality Survey of the Red River, Taos County, New Mexico, February-December 1992. New Mexico Environment Department.

Smolka, L.R. and G.Z. Jacobi. 1986. Water Quality Survey of the Red River, Taos County, New Mexico, April 15-17, 1985. New Mexico Health and Environment Department

Smolka, L.R. and D.F. Tague. 1987. Intensive Survey of the Red River, Taos County, New Mexico, August 18-21, 1986. New Mexico Health and Environment Department.

Smolka, L.R. and D.F. Tague. 1989. Intensive Water Quality Survey of the Middle Red River, Taos County, New Mexico, September 12-October 25, 1988.

South Pass Resources, Inc. 1995. Progress Report on the Geology, Hydrogeology, and Water Quality of the Mine Area, Molycorp Facility, Taos County, New Mexico. Report prepared for Molycorp, Inc.

Sparling, D.W. and T.P. Lowe. 1996. Environmental hazards of aluminum to plants, invertebrates, fish, and wildlife. *Reviews of Environmental Contamination and Toxicology* 145:1-127.

Sprague, J.B. 1968. Avoidance reactions of rainbow trout to zinc sulphate solutions. *Water Research* 2:367-372.

Steffen Robertsen and Kirsten, Inc. 1995. Questa Molybdenum Mine Geochemical Assessment and Preliminary Closure Plan. Report prepared for Molycorp, Inc.

U.S. Department of Health, Education, and Welfare. 1966. A Water Quality Survey: Red River of the Rio Grande, New Mexico. Federal Water Pollution Control Administration. Ada, Oklahoma.

U.S. EPA. 1971. A Water Quality Survey: Red River of the Rio Grande, New Mexico. Surveillance and Analysis Division. Ada, Oklahoma.

U.S. EPA. 1986. Quality Criteria for Water - 1986. Office of Water Regulations and Standards. EPA/ 440/5-86-001.

U.S. EPA. 1987. Ambient Aquatic Life Water Quality Criteria for Zinc - 1987. Office of Research and Development, EPA/440/5-87-003.

U.S. EPA. 1988. Ambient Water Quality Criteria for Aluminum - 1988. Office of Water Regulations and Standards. EPA/440/5-86-008.

Vail Engineering. 1993. Unpublished Water Quality Data for the Red River.

Vail Engineering. 1995. Unpublished Water Quality Data for the Red River.

Vail Engineering. 1997. Unpublished Water Quality Data for the Red River.

Van Deventer, J.S., and W.S. Platts. 1983. Sampling and estimating fish populations for streams. Transactions of the North American Wildlife and Natural Resources Conference. 48:349-354.

Van Deventer, J.S., and W.S. Platts. 1986. Microfish Interactive Program Version 3.0.

Wallace, J.B., J.W. Grubaugh, and M.R. Whiles. 1996. Biotic indices and stream ecosystem processes: results from an experimental study *Ecological Applications*. 6:140-151.

Wallen, E.I. 1951. The direct effect of turbidity on fishes. Bulletin of Oklahoma Agricultural and Mechanical College. Volume 48 (2).

Ward, J.V. 1975. Bottom fauna-substrate relationships in a northern Colorado trout stream: 1945 and 1974. *Ecology* 56:1425-1434.

Waters, T.F. 1995. Sediment in Streams. Sources, Biological Effects, and Control. American Fisheries Society Monograph 7. AFS. Bethesda, MD. 251 pp.

Wiederholm, T. 1989. Responses of aquatic insects to environmental pollution. pp. 508-557. IN: Resh, V.H., and D.M. Rosenberg (eds.). *The Ecology of Aquatic Insects*. Praeger Scientific, New York.

Wilhm, J.L. 1970. Range of diversity index in benthic macroinvertebrate populations. *Journal of Water Pollution Control Federation*. 42:R221-R224.

Woodward-Clyde. 1996. Red River, New Mexico, Benthic Macroinvertebrate Survey - December 1995.

APPENDIX A

FISH DATA

TABLE A1: Historical fish population data for sites on the Red River, New Mexico. Fist pass data only.

Site, Year	Species	# Collected	#/mi	#/km	Kg/km	#/ha	Kg/ha	Average Length (mm)	Average Weight (g)	# of Passes (efficiency)	Site Length (ft)	Reference
East Fork at Blue Lake Trail												
June/Aug. 1960	CUT	17	299	186	16.7	407	36.6	176	90	1 (70%)	300	NMDGF (1960)
	BRK	3	53	33	2.9	72	6.4	165	89	1 (70%)	300	NMDGF (1960)
Just Downstream of the Forks												
Nov. 1975	RBT	32	640	398	46.3	687	80.0	434	229	1	264	Parish (1975a)
	BRK	3	60	37	1.2	64	2.0	154	32	1	264	Parish (1975a)
May 1977	RBT	107	1,070	665	--	--	--	*	--	1 (90%)	528	Parish (1977b)
	CUT	2	20	12	--	--	--	*	--	1 (90%)	528	Parish (1977b)
	BRK	1	10	6	--	--	--	*	--	1 (90%)	528	Parish (1977b)
	Hybrid	2	20	12	--	--	--	*	--	1 (90%)	528	Parish (1977b)
July 1978	RBT	95	950	590	--	--	--	*	--	1 (70%)	528	Parish (1978a)
	UNK	1	10	6	--	--	--	*	--	1 (70%)	528	Parish (1978a)
Sept. 1978	RBT	24	480	298	--	--	--	*	--	1 (70%)	264	Parish (1978b)
2.0 Mi. Downstream of the Forks												
Nov. 1975	RBT	16	320	199	--	408	--	186	--	1	264	Parish (1975a)
	CUT	4	80	50	2.7	102	5.5	116	54	1	264	Parish (1975a)
	BRK	3	60	37	0.5	77	1.1	145	14	1	264	Parish (1975a)
	BRN	1	20	12	--	26	--	200	--	1	264	Parish (1975a)
	UNK	3	60	37	--	77	--	*	--	1	264	Parish (1975a)
May 1977	RBT	81	810	503	--	--	--	*	--	1 (90%)	528	Parish (1977b)
	BRK	3	30	19	--	--	--	*	--	1 (90%)	528	Parish (1977b)
	CUT	2	20	12		--	--	*	--	1 (90%)	528	Parish (1977b)
July 1978	RBT	54	540	336	--	--	--	*	--	1 (70%)	528	Parish (1978a)
	UNK	2	20	12	--	--	--	*	--	1 (70%)	528	Parish (1978a)
Sept. 1978	RBT	13	260	162	--	--	--	*	--	1	264	Parish (1978b)

TABLE A1: Continued.

Site, Year	Species	# Collected	#/mi	#/km	Kg/km	#/ha	Kg/ha	Average Length (mm)	Average Weight (g)	# of Passes (efficiency)	Site Length (ft)	Reference
2.9 Mi. Downstream of the Forks												
Nov. 1975	RBT	23	460	286	--	426	--	214	--	1	264	Parish (1975a)
	CUT	14	280	174	11.9	259	17.7	184	68	1	264	Parish (1975a)
May 1977	RBT	141	1,410	876	--	--	--	*	--	1 (90%)	528	Parish (1977b)
	CUT	7	70	43	--	--	--	*	--	1 (90%)	528	Parish (1977b)
July 1977	RBT	63	630	391	--	--	--	*	--	1 (70%)	528	Parish (1978a)
	CUT	3	30	19	--	--	--	*	--	1 (70%)	528	Parish (1978a)
Downstream of Valley of the Pines												
Aug. 1995	CUT	2	32	20	3.3	24	3.9	225	163	3	328	Akroyd (1996)
	HYB	3	48	30	3.8	36	4.6	203	127	3	328	Akroyd (1996)
	RBT	9	145	90	19.8	110	24.2	254	220	3	328	Akroyd (1996)
	BRK	10	161	100	2.9	122	3.6	89	29	3	328	Akroyd (1996)
	BRN	21	338	210	19.7	256	24.1	157	94	3	328	Akroyd (1996)
Zwergel Gaging Station												
May 1977	RBT	38	380	236	--	--	--	*	--	1 (90%)	528	Parish (1977b)
	BRK	5	50	31	--	--	--	*	--	1 (90%)	528	Parish (1977b)
	CUT	8	80	50	--	--	--	*	--	1 (90%)	528	Parish (1977b)
July 1978	RBT	40	400	248	--	--	--	*	--	1 (70%)	528	Parish (1978a)
	CUT	9	90	56	--	--	--	*	--	1 (70%)	528	Parish (1978a)
	BRK	21	210	130	--	--	--	*	--	1 (70%)	528	Parish (1978a)
	UNK	3	30	19	--	--	--	*	--	1 (70%)	528	Parish (1978a)
Sept. 1978	RBT	6	120	74	--	--	--	*	--	1	264	Parish (1978b)
	CUT	11	220	137	--	--	--	*	--	1	264	Parish (1978b)
	BRK	12	240	149	--	--	--	*	--	1	264	Parish (1978b)
	BRN	1	20	12	--	--	--	*	--	1	264	Parish (1978b)
Sept. 1980	CUT	13	229	142	8.9	--	--	172	63	n.s.	300	Melancon *et al.* (1982)
	BRK	10	176	109	6.8	--	--	159	62	n.s.	300	Melancon *et al.* (1982)
	RBT	5	88	55	7.9	--	--	237	144	n.s.	300	Melancon *et al.* (1982)

TABLE A1: Continued.

Site, Year	Species	# Collected	#/mi	#/km	Kg/km	#/ha	Kg/ha	Average Length (mm)	Average Weight (g)	# of Passes (efficiency)	Site Length (ft)	Reference
Sept. 1988	RBT	16	258	160	16.4	258	26.4	206	102	3	328	Akroyd (1988)
	CUT	7	113	70	3.3	113	5.3	148	47	3	328	Akroyd (1988)
Aug. 1996	BRN	7	113	70	9.0	146	18.7	217	128	3	328	Akroyd (1997)
	RBT	6	96	60	9.0	125	18.8	226	150	3	328	Akroyd (1997)
	CUT	29	467	290	1.0	630	2.3	60	4	3	328	Akroyd (1997)
	BRK	53	853	530	12.5	1,104	26.2	90	24	3	328	Akroyd (1997)
June Bug Campground												
Oct. 1960	RBT	13	411	255	--	--	--	211	--	1 (50%)	170	NMDGF (1960)
	BRN	7	221	137	--		--	161	--	1 (50%)	170	NMDGF (1960)
Nov. 1975	RBT	2	20	12	0.5	20	0.9	159	45	1	528	Parish (1975a)
	BRN	15	150	93	2.9	153	4.7	133	31	1	528	Parish (1975a)
	WS	1	10	6	0.5	10	0.9	203	90	1	528	Parish (1975a)
May 1977	RBT	47	470	292	--	--	--	*	--	1	528	Parish (1977b)
	BRN	3	30	19	--	--	--	*	--	1	528	Parish (1977b)
	CUT	1	10	6	--	--	--	*	--	1	528	Parish (1977b)
	BRK	2	20	12	--	--	--	*	--	1	528	Parish (1977b)
July 1978	RBT	73	730	454	--	--	--	*	--	1 (70%)	528	Parish (1978a)
	BRN	11	110	68	--	--	--	*	--	1 (70%)	528	Parish (1978a)
	BRK	4	40	25	--	--	--	*	--	1 (70%)	528	Parish (1978a)
	UNK	8	80	50	--	--	--	*	--	1 (70%)	528	Parish (1978a)
Sept. 1980	BRN	1	35	22	0.9	--	--	149	41	n.s.	150	Melancon *et al.* (1982)
	RBT	29	1,037	644	79.2	--	--	223	123	n.s.	150	Melancon *et al.* (1982)
Sept. 1983	RBT	10	200	124	--	--	--	--	--	1	264	Patterson (1983)
	BRN	4	80	50	--	--	--	--	--	1	264	Patterson (1983)
Elephant Rock Campground												
Nov. 1975	RBT	4	40	25	2.6	58	5.9	196	102	1	528	Parish (1975a)
	BRN	1	10	6	0.2	14	0.5	121	35	1	528	Parish (1975a)
May 1977	RBT	22	220	137	--	--	--	*	--	1	528	Parish (1977b)
	BRN	1	10	6	--	--	--	*	--	1	528	Parish (1977b)
July 1978	RBT	20	200	124	--	--	--	*	--	1 (70%)	528	Parish (1978a)

TABLE A1: Continued.

Site, Year	Species	# Collected	#/mi	#/km	Kg/km	#/ha	Kg/ha	Average Length (mm)	Average Weight (g)	# of Passes (efficiency)	Site Length (ft)	Reference
Sept. 1983	No fish	0	0	0	0	0	0	--	--	1	528	Patterson (1983)
Sept. 1988	BRN	5	81	50	1.8	93	3.4	143	36	3	328	Akroyd (1988)
	RBT	1	16	10	0.7	18	1.4	199	74	3	328	Akroyd (1988)
Upstream of Molycorp property boundary												
Nov. 1975	RBT	2	40	25	--	54	--	*	--	1	264	Parish (1975a)
July 1978	RBT	2	20	12	--	--	--	*	--	1 (70%)	528	Parish (1978a)
Sept. 1980	RBT	4	143	89	12.7	--	--	236	143	n.s.	150	Melancon *et al.* 1982
Aug. 1995	RBT	5	81	50	10.7	56	12.0	263	215	3	328	Akroyd (1996)
	BRN	5	81	50	4.5	56	5.0	150	89	3	328	Akroyd (1996)
Aug. 1996	RBT	2	32	20	2.5	29	3.6	231	125	3	328	Akroyd (1997)
	BRN	5	81	50	4.5	71	6.1	175	86	3	328	Akroyd (1997)
Upstream of Columbine Creek												
Oct. 1960	RBT	11	193	120	17.0	--	--	234	142	1	300	NMDGF (1960)
	BRN	5	88	55	2.8	--	--	164	51	1	300	NMDGF (1960)
Downstream of Columbine Creek												
Nov. 1975	RBT	5	100	62	6.7	88	9.6	216	109	1	264	Parish (1975a)
	CUT	5	100	62	1.3	88	1.8	126	21	1	264	Parish (1975a)
	UNK	2	40	25	--	36	--	*	--	1	264	Parish (1975a)
Sept. 1980	RBT	11	195	121	18.9	--	--	241	156	n.s.	300	Melancon *et al.* (1982)
Upstream of Goathill Gulch												
May 1977	No fish	0	0	0	0	0	0	--	--	1	528	Parish (1977b)
Goathill Campground												
Nov. 1975	RBT	6	120	74	--	--	--	*	--	1	264	Parish (1977a)
	CUT	5	100	62	--	--	--	*	--	1	264	Parish (1977a)

TABLE A1: Continued.

Site, Year	Species	# Collected	#/mi	#/km	Kg/km	#/ha	Kg/ha	Average Length (mm)	Average Weight (g)	# of Passes (efficiency)	Site Length (ft)	Reference
April 1977	BRN	4	40	25	--	--	--	*	--	1	528	Parish (1977a,b)
	RBT	69	690	429	--	--	--	*	--	1	528	Parish (1977a,b)
	CUT	1	10	6	--	--	--	*	--	1	528	Parish (1977a,b)
July 1978	RBT	11	110	68	--	--	--	*	--	1 (70%)	528	Parish (1978a)
	UNK	1	10	6	--	--	--	*	--	1 (70%)	528	Parish (1978a)
Sept. 1980	RBT	12	430	267	33.9	--	--	229	127	n.s.	148	Melancon *et al.* (1982)
Sept. 1983	RBT	2	40	25	--	--	--	--	--	1	264	Patterson (1983)
Near Mouth of Bear Canyon												
Nov. 1975	RBT	2	40	25	2.8	28	3.1	222	110	1	264	Parish (1975a, 1977a)
April 1977	No fish (2 dead RBT)	0	0	0	0	0	0	--	--	1	528	Parish (1977a,b)
July 1978	RBT	12	120	74	--	--	--	*	--	1 (70%)	528	Parish (1978a)
	WS	1	10	6	--	--	--	*	--	1 (70%)	528	Parish (1978a)
	UNK	1	10	6	--	--	--	*	--	1 (70%)	528	Parish (1978a)
Eagle Rock Campground												
July 1976	RBT	13	174	108	--	--	--	*	--	1	396	Parish (1976a)
	BRN	2	27	17	--	--	--	*	--	1	396	Parish (1976a)
	UNK	2	27	17	--	--	--	*	--	1	396	Parish (1976a)
Questa Ranger/ Gaging Station												
Sept. 1988	No fish	0	0	0	0	0	0	--	--	3	328	Akroyd (1988)
Aug. 1995	No fish	0	0	0	0	0	0	--	--	3	328	Akroyd (1996)
Aug. 1996	BRN	2	32	20	0.1	29	0.2	90	5	3	328	Akroyd (1997)
Head of Eagle Rock Lake												
Nov. 1975	BRN	4	80	50	4.7	56	5.2	224	93	1	264	Parish (1975a)
	RBT	5	100	62	9.8	70	11.1	258	158	1	264	Parish (1975a)
	WS	1	20	12	--	14	--	--	--	1	264	Parish (1975a)

TABLE A1: Continued.

Site, Year	Species	# Collected	#/mi	#/km	Kg/km	#/ha	Kg/ha	Average Length (mm)	Average Weight (g)	# of Passes (efficiency)	Site Length (ft)	Reference
July 1976	RBT	16	320	199	--	--	--	*	--	1	264	Parish (1976a, 1977a)
	BRN	5	100	62	--	--	--	*	--	1	264	Parish (1976a, 1977a)
	WS	11	220	137	--	--	--	*	--	1	264	Parish (1976a, 1977a)
	UNK	3	60	37	--	--	--	*	--	1	264	Parish (1976a, 1977a)
April 1977	WS	12	120	74	--	--	--	*	--	1	528	Parish (1977a,b)
SH 522 Bridge												
Sept. 1980	RBT	36	638	396	42.8	--	--	212	108	n.s.	300	Melancon *et al.* (1982)
	BRN	8	142	88	7.9	--	--	187	90	n.s.	300	Melancon *et al.* (1982)
	WS	2	35	22	1.7	--	--	185	75	n.s.	300	Melancon *et al.* (1982)
Upstream of hatchery diversion												
Oct. 1960	BRN	6	317	197	--	--	--	311	--	1 (20%)	100	NMDGF (1960)
July 1976	RBT	22	440	273	--	--	--	*	--	1	264	Parish (1976a)(conflicting site location)
	BRN	10	200	124	--	--	--	*	--	1	264	Parish (1976a)(conflicting site location)
Sept. 1980	BRN	17	299	186	16.7	--	--	162	90	n.s.	300	Melancon *et al.* (1982)
	RBT	6	106	66	4.5	--	--	180	68	n.s.	300	Melancon *et al.* (1982)
Nov. 1986	BRN	9	238	148	--	--	--	*	--	1	200	Akroyd (1987a)
	RBT	17	449	279	--	--	--	*	--	1	200	Akroyd (1987a)
Sept. 1987	BRN	11	290	180	--	--	--	*	--	1	200	Akroyd (1987b)
	RBT	1	26	16	--	--	--	*	--	1	200	Akroyd (1987b)
Sept. 1988	BRN	36	950	590	--	--	--	*	--	1	200	Akroyd (1988)
	RBT	13	343	213	--	--	--	*	--	1	200	Akroyd (1988)
Sept. 1995	RBT	16	234	145	14.1	132	12.8	206	97	3	361	Akroyd (1996)
	BRN	13	190	118	5.8	107	5.2	138	49	3	361	Akroyd (1996)
Aug. 1996	BRN	86	1,384	860	16.0	988	18.4	107	19	3	328	Akroyd (1997)
	RBT	14	225	140	13.9	161	16.0	201	99	3	328	Akroyd (1997)

TABLE A1: Continued.

Site, Year	Species	# Collected	#/mi	#/km	Kg/km	#/ha	Kg/ha	Average Length (mm)	Average Weight (g)	# of Passes (efficiency)	Site Length (ft)	Reference
Downstream of hatchery diversion												
July 1976	BRN	10	200	124	--	--	--	*	--	1	264	Parish (1977a)(conflicting site location)
	RBT	22	440	273	--	--	--	*	--	1	264	Parish (1977a)(conflicting site location)
April 1977	BRN	45	450	280	--	--	--	*	--	1	528	Parish (1977a)
	RBT	81	810	503	--	--	--	*	--	1	528	Parish (1977a)
Nov. 1986	BRN	30	792	492	--	--	--	*	--	1	200	Akroyd (1987a)
	RBT	17	449	279	--	--	--	*	--	1	200	Akroyd (1987a)
Sept. 1987	BRN	33	871	541	--	--	--	*	--	1	200	Akroyd (1987b)
	RBT	3	79	49	--	--	--	*	--	1	200	Akroyd (1987b)
Sept. 1988	BRN	47	1,241	771	--	--	--	*	--	1	200	Akroyd (1988)
	RBT	24	634	394	--	--	--	*	--	1	200	Akroyd (1988)
Downstream of hatchery												
June 1981	BRN	13	130	81	--	--	--	*	--	1 (50%)	528	Akroyd (1984)
	RBT	16	160	99	--	--	--	*	--	1 (50%)	528	Akroyd (1984)
Sept. 1984	BRN	23	230	143	--	--	--	*	--	1 (50%)	528	Akroyd (1984)
	RBT	14	140	87	--	--	--	*	--	1 (50%)	528	Akroyd (1984)
Aug. 1985	BRN	11	110	68	--	--	--	*	--	1 (50%)	528	Akroyd (1985)
	RBT	1	10	6	--	--	--	*	--	1 (50%)	528	Akroyd (1985)
	UNK	4	40	25	--	--	--	*	--	1 (50%)	528	Akroyd (1985)
Nov. 1986	BRN	122	1,220	758	--	--	--	*	--	1 (50%)	528	Akroyd (1987a)
	RBT	108	1,080	671	--	--	--	*	--	1 (50%)	528	Akroyd (1987a)
Sept. 1987	BRN	37	370	230	--	--	--	*	--	1 (50%)	528	Akroyd (1987b)
	RBT	22	220	137	--	--	--	*	--	1 (50%)	528	Akroyd (1987b)
Sept. 1988	BRN	108	1,080	671	--	--	--	*	--	1 (50%)	528	Akroyd (1988)
	RBT	14	140	87	--	--	--	*	--	1 (50%)	528	Akroyd (1988)
	UNK	8	80	50	--	--	--	*	--	1 (50%)	528	Akroyd (1988)

TABLE A1: Continued.

Site, Year	Species	# Collected	#/mi	#/km	Kg/km	#/ha	Kg/ha	Average Length (mm)	Average Weight (g)	# of Passes (efficiency)	Site Length (ft)	Reference
Between hatchery and El Aujae Campground												
Oct. 1974	RBT	331	2,207	1,371	--	--	--	*	--	1 (50%)	792	Patterson (1974)
	BRN	36	240	149	--	--	--	*	--	1 (50%)	792	Patterson (1974)
	WS	4	27	17	--	--	--	*	--	1 (50%)	792	Patterson (1974)
Nov. 1979	RBT	8	160	99	--	--	--	*	--	1 (50%)	264	Parish (1979)
	BRN	25	500	311	--	--	--	*	--	1 (50%)	264	Parish (1979)
	UNK	1	20	12	--	--	--	*	--	1 (50%)	264	Parish (1979)
June 1981	BRN	46	230	143	--	--	--	*	--	1 (50%)	1,056	Akroyd (1984)
	RBT	24	120	75	--	--	--	*	--	1 (50%)	1,056	Akroyd (1984)
Feb. 1984	BRN	7	70	43	--	--	--	*	--	1	528	Patterson (1984)
	UNK	1	10	6	--	--	--	*	--	1	528	Patterson (1984)
Sept. 1984	BRN	60	300	186	--	--	--	*	--	1 (50%)	1,056	Akroyd (1984)
	RBT	14	70	43	--	--	--	*	--	1 (50%)	1,056	Akroyd (1984)
	UNK	1	5	3	--	--	--	*	--	1 (50%)	1,056	Akroyd (1984)
Aug. 1985	BRN	32	160	99	--	--	--	*	--	1 (50%)	1,056	Akroyd (1985)
	RBT	1	5	3	--	--	--	*	--	1 (50%)	1,056	Akroyd (1985)
	UNK	7	35	22	--	--	--	*	--	1 (50%)	1,056	Akroyd (1985)
Nov. 1986	BRN	209	1,045	649	--	--	--	*	--	1 (50%)	1,056	Akroyd (1987a)
	RBT	15	75	47	--	--	--	*	--	1 (50%)	1,056	Akroyd (1987a)
Sept. 1987	BRN	101	505	314	--	--	--	*	--	1 (50%)	1,056	Akroyd (1987b)
	RBT	13	65	40	--	--	--	*	--	1 (50%)	1,056	Akroyd (1987b)
	UNK	6	30	19	--	--	--	*	--	1 (50%)	1,056	Akroyd (1987b)
Sept. 1988	BRN	241	1,205	749	--	--	--	*	--	1 (50%)	1,056	Akroyd (1988)
	UNK	2	10	6	--	--	--	*	--	1 (50%)	1,056	Akroyd (1988)
El Aujae Campground												
Sept. 1976	RBT	24	480	298	--	--	--	*	--	1 (75%)	264	Parish (1976b)
	BRN	31	620	385	--	--	--	*	--	1 (75%)	264	Parish (1976b)
June 1981	BRN	11	110	68	--	--	--	*	--	1 (50%)	528	Akroyd (1984)
	RBT	46	460	286	--	--	--	*	--	1 (50%)	528	Akroyd (1984)

TABLE A1: Continued.

Site, Year	Species	# Collected	#/mi	#/km	Kg/km	#/ha	Kg/ha	Average Length (mm)	Average Weight (g)	# of Passes (efficiency)	Site Length (ft)	Reference
Sept. 1984	BRN	20	200	124	--	--	--	*	--	1 (50%)	528	Akroyd (1984)
	RBT	2	20	12	--	--	--	*	--	1 (50%)	528	Akroyd (1984)
Aug. 1985	BRN	16	160	99	--	--	--	*	--	1 (50%)	528	Akroyd (1985)
	RBT	1	10	6	--	--	--	*	--	1 (50%)	528	Akroyd (1985)
Nov. 1986	BRN	69	690	429	--	--	--	*	--	1 (50%)	528	Akroyd (1987a)
	RBT	5	50	31	--	--	--	*	--	1 (50%)	528	Akroyd (1987a)
Sept. 1987	BRN	54	540	336	--	--	--	*	--	1 (50%)	528	Akroyd (1987b)
	RBT	4	40	25	--	--	--	*	--	1 (50%)	528	Akroyd (1987b)
Sept. 1988	BRN	121	1,210	752	--	--	--	*	--	1 (50%)	528	Akroyd (1988)
	RBT	1	10	6	--	--	--	*	--	1 (50%)	528	Akroyd (1988)
	UNK	4	40	25	--	--	--	*	--	1 (50%)	528	Akroyd (1988)
La Junta Point												
Nov. 1979	RBT	6	120	74	--	--	--	*	--	1 (40%)	264	Parish (1979)
	BRN	18	360	224	--	--	--	*	--	1 (40%)	264	Parish (1979)
	WS	11	220	137	--	--	--	*	--	1 (40%)	264	Parish (1979)
	Chub	2	40	25	--	--	--	*	--	1 (40%)	264	Parish (1979)
June 1981	BRN	19	190	118	--	--	--	*	--	1 (50%)	528	Akroyd (1984)
	RBT	18	180	112	--	--	--	*	--	1 (50%)	528	Akroyd (1984)
Sept. 1984	BRN	29	290	180	--	--	--	*	--	1 (50%)	528	Akroyd (1984)
	RBT	3	30	19	--	--	--	*	--	1 (50%)	528	Akroyd (1984)
	UNK	2	20	12	--	--	--	*	--	1 (50%)	528	Akroyd (1984)
Aug. 1985	BRN	22	220	137	--	--	--	*	--	1 (50%)	528	Akroyd (1985)
	RBT	20	200	124	--	--	--	*	--	1 (50%)	528	Akroyd (1985)
	UNK	5	50	31	--	--	--	*	--	1 (50%)	528	Akroyd (1985)

*Divided into 2-3" size classes.
n.s. = not specified.
Data from Akroyd (1988, 1996, 1997) includes only 1st pass.

APPENDIX B

BENTHIC INVERTEBRATE DATA

TABLE B1: Historical benthic invertebrate population data for sites on the Red River, New Mexico.

Site, Date	# of Taxa	% EPT Taxa	#/m²	g/m²	Biotic Indices	Reference
East Fork at Blue Lake Trail						
June 1960	9	78	542	--	1.47 cm³/m²	NMDFG (1960)
Zwergel Gaging Station						
Sept. 1980	27	59	K	--	--	Melancon *et al.* (1982)
April 1985	27	63	2,501	--	H' = 3.60 CTQ_a = 48 BCI = 104	Smolka & Jacobi (1986)
Aug. 1986	16	69	1,567	--	H' = 3.03 CTQ_a = 44 BCI = 112	Smolka & Tague (1987)
Sept. 1988	28	61	2,038	--	H' = 3.77 CTQ_a = 48 BCI = 104	Smolka & Tague (1989)
April 1992	31	64	2,765	--	H' = 3.64 CTQ_a = 46 BCI = 110	Smolka (1993)
Upstream of Bitter Creek						
Nov. 1965	22	77	1,044	--	--	USFWPCA (1966)
Nov. 1970	17	--	3,548	--	BBI = 30	USEPA (1971)
April 1992	29	59	3,090	--	H' = 3.45 CTQ_a = 45 BCI = 111	Smolka (1993)
Dec. 1995	48	48	10,121	--	EPT/Chiron = 19.3 HBI = 2.72 H' = 2.80 % scrapers = 35.2 % filterers = 1.6	Woodward-Clyde (1996)
Downstream of Bitter Creek						
Nov. 1965	20	90	1,267	--	--	USFWPCA (1966)
Nov. 1970	16	--	2,971	--	BBI = 31	USEPA (1971)
April 1992	26	65	2,551	--	H' = 3.46 CTQ_a = 47 BCI = 107	Smolka (1993)
Downstream of Red River						
Dec. 1995	40	53	2,616	--	EPT/Chiron. = 7.3 HBI = 3.83 H' = 3.67 % scrapers = 17.8 % filterers = 12.5	Woodward-Clyde (1996)

TABLE B1: Continued.

Site, Date	# of Taxa	% EPT Taxa	#/m^2	g/m^2	Biotic Indices	Reference
June Bug Campground						
Sept. 1980	25	68	K	--	--	Melancon *et al.* (1982)
Jan. 1984	22	68	2,071	--	H' = 3.13 CTQ_a = 36	Jacobi & Smolka (1984)
Aug. 1986	21	71	1,145	--	H' = 3.33 CTQ_a = 41 BCI = 125	Smolka & Tague (1987)
Sept. 1988	14	64	771	--	H' = 2.59 CTQ_a = 41 BCI = 123	Smolka & Tague (1989)
April 1992	20	65	1,835	--	HBI = 2.14 H' = 3.13 CTQ_a = 49 BCI = 103	Smolka (1993)
Elephant Rock Campground						
Nov. 1970	17	--	1,152	--	BBI = 29	USEPA (1971)
Sept. 1980	27	67	K	--	--	Melancon *et al.* (1982)
April 1985	21	67	916	--	H' = 3.79 CTQ_a = 37 BCI = 136	Smolka & Jacobi (1986)
Aug. 1986	23	70	2,090	--	H' = 3.15 CTQ_a = 43 BCI = 118	Smolka & Tague (1987)
Sept. 1988	16	62	997	--	H' = 2.92 CTQ_a = 42 BCI = 135	Smolka & Tague (1989)
April 1992	18	72	1,407	--	HBI = 2.48 H' = 2.71 CTQ_a = 44 BCI = 113	Smolka (1993)
Dec. 1995	34	53	4,030	--	EPT/Chiron = 2.6 HBI = 4.48 H' = 3.40 % scrapers = 12.4 % filterers = 8.0	Woodward-Clyde (1996)
Upstream of Molycorp property boundary						
Nov. 1965	17	71	337	--	--	USFWPCA (1966)
May 1971	5	60	99	1.7	--	Pennak (1972)
June 1971	9	78	210	4.2	--	Pennak (1972)
July 1971	9	89	109	4.0	--	Pennak (1972)
Sept. 1971	9	78	90	2.7	--	Pennak (1972)
Oct. 1971	4	100	29	0.8	--	Pennak (1972)

TABLE B1: Continued.

Site, Date	# of Taxa	% EPT Taxa	#/m²	g/m²	Biotic Indices	Reference
Nov. 1971	10	70	160	2.9	--	Pennak (1972)
Oct. 1976	--	--	562	6.0	--	Pennak (1976)
Mar. 1977	--	--	787[a]	1.7	--	Pennak (1977a)
Oct. 1977	--	--	56	0.7	--	Pennak (1977b)
Mar. 1978	--	--	959	7.3	--	Pennak (1978)
Aug. 1979	--	--	--	1.6	--	Pennak (1979)
Sept. 1979	--	--	--	0.4	--	Pennak (1979)
Sept. 1980	18	72	K	--	--	Melancon *et al.* (1982)
July 1981	--	--	--	26.5	--	Pennak (1981)
Oct. 1982	--	--	--	4.4	--	Pennak (1983)
Oct. 1983	--	--	--	2.7	--	Pennak (1984)
Sept. 1988	16	62	1,275	--	H' = 2.82 CTQ_a = 42 BCI = 119	Smolka & Tague (1989)
Oct. 1988	10	90	230	--	H' = 2.92 CTQ_a = 29 BCI = 172	ENSR. (1988)
April 1992	13	62	1,594	--	HBI = 2.59 H' = 2.41 CTQ_a = 52 BCI = 97	Smolka (1993)
Downstream of Hansen Creek, Upstream of Sulphur Gulch						
Dec. 1995	26	58	1,177	--	EPT/Chiron. = 5.9 HBI = 4.77 H' = 3.62 % scrapers = 11.1 % filterers = 24.0	Woodward-Clyde (1996)
Downstream of Columbine Creek						
Sept. 1980	26	70	K	--	--	Melancon *et al.* (1982)
Dec. 1995	36	64	1,614	--	EPT/Chiron. = 6.0 HBI = 4.01 H' = 3.54 % scrapers = 17.1 % filterers = 28.5	Woodward-Clyde (1996)
Upstream of Goathill Gulch						
Nov. 1965	14	71	402	--	--	USFWPCA (1966)
Nov. 1970	11	--	933	--	BBI = 21	USEPA (1971)

TABLE B1: Continued.

Site, Date	# of Taxa	% EPT Taxa	#/m²	g/m²	Biotic Indices	Reference
Dec. 1995	18	78	600	--	EPT/Chiron. = 0.7 HBI = 7.02 H' = 2.01 % scrapers = 1.3 % filterers = 14.1	Woodward-Clyde (1996)
Goathill Campground						
Oct. 1976	--	--	808[b]	6.5	--	Pennak (1976)
Mar. 1977	--	--	211	4.5	--	Pennak (1977a)
Oct. 1977	--	--	43	0.3	--	Pennak (1977b)
Mar. 1978	--	--	1,677	32.3	--	Pennak (1978)
July 1978	--	--	443	5.2	--	Pennak (1978)
Aug. 1979	--	--	--	0.6	--	Pennak (1979)
Sept. 1979	--	--	--	0.6	--	Pennak (1979)
Sept. 1980	20	75	K	--	--	Melancon *et al.* (1982)
July 1981	--	--	--	3.0	--	Pennak 1981
Oct. 1982	--	--	--	1.9	--	Pennak (1983)
Oct. 1983	--	--	--	1.5	--	Pennak (1984)
Oct. 1988	6	83	79	--	H' = 1.96 CTQ_a = 31 BCI = 164	ENSR. (1988)
Upstream of Capulin Canyon						
Dec. 1995	17	65	319	--	EPT/Chiron. = 14.3 HBI = 3.83 H' = 3.26 % scrapers = 14.8 % filterers = 13.8	Woodward-Clyde (1996)
Eagle Rock Campground						
May 1971	5	80	31	2.9	--	Pennak (1972)
June 1971	5	40	74	1.1	--	Pennak (1972)
July 1971	8	50	59	2.9	--	Pennak (1972)
Sept. 1971	6	67	50	1.3	--	Pennak (1972)
Oct. 1971	8	88	149	3.5	--	Pennak (1972)
Nov. 1971	7	71	50	2.3	--	Pennak (1972)
Oct. 1976	--	--	170	1.4	--	Pennak (1976)
Mar. 1977	--	--	555[c]	7.8	--	Pennak (1977a)
Oct. 1977	--	--	82	2.4	--	Pennak (1977b)
Mar. 1978	--	--	52	0.5	--	Pennak (1978)
July 1978	--	--	490	16.3	--	Pennak (1978)
Aug. 1979	--	--	--	0.2	--	Pennak (1979)
Sept. 1979	--	--	--	1.0	--	Pennak (1979)
July 1981	--	--	--	1.5	--	Pennak (1981)
Oct. 1982	--	--	--	1.4	--	Pennak (1983)
Oct. 1983	--	--	--	2.4	--	Pennak (1984)

TABLE B1: Continued.

Site, Date	# of Taxa	% EPT Taxa	#/m^2	g/m^2	Biotic Indices	Reference
Questa Ranger/ Gaging Station						
Nov. 1965	9	67	83	--	--	USFWPCA (1966)
Nov. 1970	11	--	448	--	BBI = 19	USEPA (1971)
Sept. 1988	6	100	171	--	H' = 2.06 CTQ_a = 32	Smolka & Tague (1989)
Oct. 1988	3	100	108	--	H' = 1.30 CTQ_a = 31 BCI = 161	ENSR. (1988)
April 1992	10	60	490	--	HBI = 1.26 H' = 1.18 CTQ_a = 46 BCI = 108	Smolka (1993)
Dec. 1995	16	69	456	--	EPT/Chiron. = 6.8 HBI = 4.56 H' = 2.49 % scrapers = 4.0 % filterers = 6.1	Woodward-Clyde (1996)
SH 522 Bridge						
Nov. 1965	6	67	108	--	--	USFWPCA (1966)
Nov. 1970	10	--	818	--	BBI = 19	USEPA (1971)
Sept. 1980	22	73	K	--	--	Melancon *et al.* (1982)
April 1985	17	59	388	--	H' = 3.48 CTQ_a = 45 BCI = 112	Smolka & Jacobi (1986)
Aug. 1986	17	71	607	--	H' = 3.34 CTQ_a = 42 BCI = 119	Smolka & Tague (1987)
April 1992	13	69	535	--	HBI = 2.60 H' = 2.43 CTQ_a = 50 BCI = 100	Smolka (1993)
Dec. 1995	22	55	2,605	--	EPT/Chiron = 4.9 HBI = 6.32 H' = 2.39 % scrapers = 1.5 % filterers = 3.8	Woodward-Clyde (1996)
Upstream of Pope Creek						
May 1971	11	82	290	7.14	--	Pennak (1972)
June 1971	5	40	216	3.78	--	Pennak (1972)
July 1971	8	75	326	5.04	--	Pennak (1972)
Sept. 1971	8	75	82	0.84	--	Pennak (1972)
Oct. 1971	8	88	147	2.10	--	Pennak (1972)
Nov. 1971	8	88	617	3.36	--	Pennak (1972)
Oct. 1976	--	--	765	6.6	--	Pennak (1976)

TABLE B1: Continued.

Site, Date	# of Taxa	% EPT Taxa	#/m²	g/m²	Biotic Indices	Reference
Mar. 1977	--	--	2,018	17.3	--	Pennak (1977a)
Oct. 1977	--	--	159	1.1	--	Pennak (1977b)
Mar. 1978	--	--	907	6.2	--	Pennak (1978)
July 1978	--	--	211	1.8	--	Pennak (1978)
Aug. 1979	--	--	--	2.4	--	Pennak (1979)
Sept. 1979	--	--	--	2.0	--	Pennak (1979)
July 1981	--	--	--	6.7	--	Pennak (1981)
Oct. 1982	--	--	--	14.0	--	Pennak (1983)
Oct. 1983	--	--	--	6.9	--	Pennak (1984)
Oct. 1988	11	64	362	--	H' = 2.68 CTQ_a = 61 BCI = 82	ENSR. (1988)
Downstream of Pope Creek						
Dec. 1995	29	55	3,891	--	EPT/Chiron = 6.5 HBI = 6.26 H' = 2.44 % scrapers = 2.4 % filterers = 4.3	Woodward-Clyde (1996)
Upstream of hatchery diversion						
June 1960	12	67	1,650	--	28.6 cm³/m²	NMDFG (1960)
Nov. 1965	10	50	291	--	--	USFWPCA (1966)
Nov. 1970	16	--	2,759	--	BBI = 27	USEPA (1971)
May 1971	9	78	299	10	--	Pennak (1972)
June 1971	7	71	479	16	--	Pennak (1972)
July 1971	8	62	199	--	--	Pennak (1972)
Sept. 1971	6	50	571	--	--	Pennak (1972)
Oct. 1971	5	60	479	10.9	--	Pennak (1972)
Nov. 1971	7	57	84	--	--	Pennak (1972)
Oct. 1976	--	--	632	5.8	--	Pennak (1976)
Mar. 1977	--	--	1,875	51.6	--	Pennak (1977a)
Oct. 1977	--	--	224	2.5	--	Pennak (1977b)
Mar. 1978	--	--	1,402	18.5	--	Pennak (1978)
July 1978	--	--	2,207	21.1	--	Pennak (1978)
Aug. 1979	--	--	--	3.4	--	Pennak (1979)
Sept. 1979	--	--	--	1.0	--	Pennak (1979)
July 1981	--	--	--	4.9	--	Pennak (1981)
Oct. 1982	--	--	--	2.8	--	Pennak (1983)
Oct. 1983	--	--	--	6.9	--	Pennak (1984)
Oct. 1988	11	64	495	--	H' = 2.56 CTQ_a = 59 BCI = 84	ENSR. (1988)

TABLE B1: Continued.

Site, Date	# of Taxa	% EPT Taxa	#/m²	g/m²	Biotic Indices	Reference
Dec. 1995	34	41	4,449	--	EPT/Chiron = 13.5 HBI = 6.22 H' = 2.08 % scrapers = 1.1 % filterers = 5.5	Woodward-Clyde (1996)
Downstream of hatchery						
April 1992	19	63	1,423	--	H' = 3.19 CTQ_a = 53 BCI = 93	Smolka (1993)
Between hatchery and El Aujae Campground						
Nov. 1965	20	50	344	--	--	USFWPCA (1966)
Nov. 1970	19	--	3,523	--	BBI = 26	USEPA (1971)
Aug. 1979	--	--	--	1.7	--	Pennak (1979)
Sept. 1979	--	--	--	1.4	--	Pennak (1979)
July 1981	--	--	--	6.7	--	Pennak (1981)
Oct. 1982	--	--	--	9.8	--	Pennak (1983)
Oct. 1983	--	--	--	6.0	--	Pennak (1984)
April 1985	20	75	2,047	--	H' = 2.29 CTQ_a = 51 BCI = 98	Smolka & Jacobi (1986)
Aug. 1986	17	65	1,836	--	H' = 2.70 CTQ_a = 43 BCI = 117	Smolka & Tague (1987)
Oct. 1988	12	58	1,973	--	H' = 1.66 CTQ_a = 50 BCI = 99	ENSR. (1988)
Dec. 1995	45	51	6,012	--	EPT/Chiron = 15.1 HBI = 6.40 H' = 2.42 % scrapers = 1.3 % filterers = 8.0	Woodward-Clyde (1996)
La Junta Point						
Oct. 1988	10	70	K	--	--	ENSR. (1988)

EPT/Chiron. = ratio of EPT taxa to Chironomidae taxa
HBI = Hilsenhoff Biotic Index
H' = Shannon-Weiner Diversity Index
CTQ_a = Community Tolerance Quotient (CTQ_p for all sites = 50)
BCI = Biotic Condition Index
BBI = Beck Biotic Index
K = kick sample (qualitative)
[a] Published value miscalculated as 112/m²
[b] Published value miscalculated as 763/m²
[c] Calculated value approximately 112/m²

Expert Report – William M. Schafer, Ph.D.

1. Summary of Qualifications

1.1 Employment and Title

Dr. William M. Schafer is founder and President of Schafer & Associates, an environmental consulting firm specializing in mining environmental issues.

1.2 Qualifications, Education, Experience, and Publications

Dr. Schafer received a B.S. degree in watershed science from Colorado State University, a M.S. degree in soil science from the University of California at Davis, and a Ph.D. in soil science from Montana State University. Dr. Schafer worked at Montana State University as Research Associate and Assistant Professor from 1975 until 1985, during which time he conducted research on mined land revegetation and reclamation, mining geochemistry, and mining hydrology. As a consultant, he has been involved in over 200 projects relating to mining environmental management. He has authored or co-authored numerous papers, symposium presentations, and technical short-courses over the last ten years. Dr. Schafer's resume including a list of all articles published in the last ten years is attached.

1.3 Compensation

Hourly rate is $140 per hour.

1.4 Appeared as Witness in Past 4 years

- (Friends of Santa Fe County v LAC Minerals (USA) Inc et al. (US District Court for New Mexico): Expert witness for LAC Minerals regarding the Ortiz Mine
- Expert witness in a Montana water rights claim
- State of Montana v ARCO et al. (US District Court for Montana) Factual witness for the ARCO Clark Fork River Natural Resource Damage suit (pending)

2. Sources of Information

My opinion is based on a detailed review of a number of documents and reports, (listed in References Cited Section 5), detailed analysis and interpretation of selected data contained in the aforementioned reports, a visit to the Molycorp site and the surrounding vicinity including the Red River, and inspection of selected reaches of tributary basins. In addition, I reviewed the expert reports submitted by Mr. Richard Kelsey dated March 14,1997; Dr. Leland Mink dated March 13, 1997; and Ms. Barbara Williams dated March 13, 1997.

3. Summary

1. Flow in the Red River consists of two components; surface runoff and groundwater. Surface runoff from the mined area is controlled by the stormwater management system. As a result, the mine has reduced that portion of the natural metal and sulfate loads to the Red River that before mining were carried by surface runoff. Groundwater contributions to flow, also known as "baseflow", vary by as much as ten-fold on different days within a single year. Additionally, the average annual groundwater baseflow can vary by a factor of two or more. Baseflow contribution from the reach of the Red River adjacent to the mining area measured in November 1965 and November 1988 by United States Geological Survey (USGS) fall within the natural range of variability. Consequently, based on my review of available information, I do not believe that baseflow contribution has changed as a result of Molycorp's activities.

2. Changes in annual precipitation correspond with changes in groundwater baseflow. Consequently, increased annual precipitation for the period 1980 to present (Slifer 1996), would tend to increase groundwater baseflow, resulting in increased loads of sulfate, TDS and metals from natural hydrothermal scar areas to the Red River.

3. Despite increased precipitation from 1980 to present, available flow and chemical data from the Red River do not identify a trend for increasing

metal, total dissolved solids (TDS) or sulfate levels since development of the open pit in late 1965 through 1981. Reliable data on metal concentrations in the Red River are not available prior to the 1970's. Calculated loads and concentrations of TDS since 1965 are within normal ranges of variability and are due to changes in precipitation and other natural factors. Changes in sulfate load and concentration through time are small. In addition, sulfate loads to the Red River are contributed over a diffuse zone several miles long – starting above the mine, and continuing in the reach adjacent to the mine, and continuing downgradient of the mine. Similar proportional changes in sulfate occur both above and adjacent to the mine. Consequently, changes in sulfate cannot be shown to result from mining at the Molycorp site.

A number of complex processes may affect the metal loads in rivers including precipitation, deposition in the bed, re-suspension, and adsorption or dissolution from adsorbed phases into dissolved phases. Consequently, these processes must be considered when determining the source of metal loads. Most metal loads in the Red River increase in a downstream direction, but the pattern of load increase does not indicate that the mine area is a source of the metals. Changes in metal concentrations are more consistent with contribution from hydrothermal scars that occur over a zone starting well above and ending well below the mine area. The changes in the load of some metals, especially iron, are caused by re-suspension of precipitates in the streambed.

4. Water in contact with either mine waste rock or natural hydrothermal scars has the same geochemical "signature". Consequently, increases in the concentration of specific metals such as zinc or manganese in seeps or in the Red River adjacent to the mine do not indicate that seepage was contributed by mine waste rock sources.

5. The metal concentration in seeps adjacent to the Red River is controlled by the ambient pH of the groundwater system. Consequently, differences in the chemistry of water contacting mine waste rock or hydrothermal scars, if present, would not cause similar differences in the

chemistry of groundwater seeps. Based on the natural chemical evolution of groundwater, recharge from scar areas would be expected to have poorer chemistry than recharge through mine waste rock.

6. There is no geochemical basis for determining the location, timing or amount of acidic drainage and associated constituents, also known as acid rock drainage (ARD), contributed to the Red River by the mine waste rock.

4. Basis of opinion

4.1 Red River Flow Regime

1. Surface water in the Red River is derived from surface runoff and from groundwater "baseflow" contributions (Dunne and Leopold 1978). In mountain streams, surface runoff occurs during seasonal snowmelt events and in response to large rainstorms. Baseflow is more continuous and accounts for all of the flow in perennial streams for most of the year. There are a number of mathematic al and graphical methods for estimating groundwater recharge to streams by separating the baseflow contribution from surface runoff (Mau and Winter 1997).

   For example, flow data from the Red River gauge near Questa were used and baseflow was determined graphically for a low flow (1978, Figure 1) and a higher flow year (1984, Figure 2). The variation in estimated daily baseflow for the entire hydrologic basin just below the mine site varied from 2 to 50 cubic feet per second (cfs) in 1978, and from 10 to 100 cfs in 1984. Similar seasonal variations in baseflow would be expected for groundwater contributions from the reach adjacent to the Molycorp mine. Variations in average annual baseflow varied from of 14 to 27 cfs, or 0.14 to 0.27 feet of groundwater recharge averaged over the basin area.

   Using data collected by Vail Engineering in 1992 and 1995, Smolke and Tague in 1988, EPA in 1970, and US Public Health Service in 1965, the baseflow contribution for the reach adjacent to the mine can be estimated by subtracting upstream and tributary flows from downstream flows. Baseflow was 4.0, 3.2 and 3.1 cfs in 1988, 1993 and 1995 respectively. In some years specific segments of the Red River near the Molycorp mine have been losing reaches. During the earlier years, Columbine Creek was not gauged, however, in 1970 (a low flow year) the reach lost 1.5 cfs of flow even without accounting for Columbine Creek. If Columbine Creek flow was assumed to be 3 cfs, then the Red River reach adjacent to the mine lost 4.5 cfs in 1970. In 1965, the reach contributed 4.3 cfs of baseflow if Columbine flow was assumed to be 5 cfs.

2. Mink and Kelsey each referred to USGS studies of the groundwater contribution to the Red River conducted in 1965 and in 1988. Mink quoted the 1988 USGS report inaccurately when he reported a groundwater seepage contribution of 4 cfs in the reach bordering Molycorp. The 4 cfs increase in flow actually occurred upstream of the mill. Actual baseflow contribution in 1988 was a loss of 1 cfs between the mill and Columbine Creek and a gain of 3.7 cfs below Columbine Creek, for a total contribution of 2.7 cfs.

3. The baseflow contribution rate for any mountain stream would be expected to vary within any year by up to ten-fold (Mau and Winter 1997). Consequently, variations in baseflow such as those observed between 1965 and 1988 in the Red River are common for any two single day measurements of baseflow collected in two different years. This observation cannot be construed as a trend indicating change in groundwater baseflow due to the Molycorp mine.

4.2 Geochemical Conditions in the Red River

1. The concentrations of many constituents in the Red River increase in a downstream direction. Williams attributed the increases in sulfate, TDS, and metal concentration to the waste rock piles at the Molycorp mine site. Evidence offered that the Molycorp waste rock piles were the primary source includes: (i) constituents have increased since development of the open pit; (ii) constituents are elevated in water in contact with waste rock;

and (iii) the mine has covered a large extent of hydrothermal scars, a natural source of sulfate, TDS and metal loading. Additionally, the concentrations of metals in water contacting waste rock was said to have a different "signature" than water in contact with hydrothermal scars. Specifically, she contended that water contacting mine waste rock had higher concentrations of manganese and zinc.

2. I conducted a detailed review of the sulfate, TDS and metal concentrations in the Red River. I used data from several sources to determine the "mass loads" in the Red River upgradient, adjacent to, and downgradient of the Molycorp Mine. Information sources include Public Health Service 1966, EPA 1971, Smolka and Tague 1989, Vail Engineering 1993, and Woodward Clyde 1996. These data were used because they span the available period of record, and because they came from a variety of sources. The mass loads of each constituent (grams/second) were calculated by multiplying the concentration measured in samples collected from various stations along the Red River by the measured flow rate. Mass loads were determined at several stations upgradient of the Molycorp Mine starting above the town of Red River (near Highway 38 mile marker 13) continuing to above the mill (between mile marker 7 and 8). Several monitoring stations were also sampled adjacent to the Molycorp Mine, from the mill downstream to the mouth of Capulin Canyon (near mile marker 3). Finally, several stations below the mine but above the town of Questa were sampled. In the earlier sampling events, fewer stations were monitored. Nonetheless, mass loads were calculated for total dissolved solids (TDS), sulfate, alkalinity, aluminum, iron, manganese, and zinc for all available stations (Figures 1 through 7).

3. There is significant variation in the TDS load in the river between measurements taken from 1965 to 1995 (Figure 3a and 3b). Higher TDS loads occur during periods of higher flow October 1988 and November 1995, and lower TDS occurs during low flow (such as in 1970 when flow was only 11.7 cfs at the Ranger Station). There is a relatively consistent increase in TDS in a downstream direction. During periods of high flow, the TDS load increases from 40 g/s to 100 g/s between the town of Red

River and the station just above the Molycorp mill. These increases in TDS are not caused by the mine. The sources of elevated TDS along this 5 mile reach are hydrothermal scars located mostly north of the river (South Pass 1995, SRK 1995, Vail Engineering 1994, Woodward Clyde 1996).

Along the next 4 mile reach, TDS increases by 75 grams per second (g/s). Possible sources of TDS include groundwater recharge through the Molycorp mine waste rock, runoff and groundwater flow through exposed hydrothermal scars (or debris flow fan delta deposits derived from scar areas), groundwater flow through bedrock, or groundwater flow through hydrothermal scar areas that have been buried by mine facilities. Surface water runoff from the mine facilities is prevented from directly entering the Red River.

Additionally, a significant portion of the groundwater flow to the north of this reach of the Red River is collected by mine dewatering. The groundwater intercepted by passive and active mine dewatering may intercept both mine-affected groundwater as well as groundwater with naturally elevated TDS levels. Downgradient of the Molycorp Mine, the TDS levels continue to increase. Exposed hydrothermal scars further west of the mine areas accounts for these loads. Variations in the TDS load and concentration are best explained by natural variation in rainfall and other natural factors.

4. The sulfate loads follow the same pattern as TDS (Figure 4). This is not surprising because sulfate is the primary anion dissolved in the Red River so differences in TDS should parallel those of sulfate. Differences in sulfate load are strongly affected by the flow rate, with small sulfate loads observed during periods of low flow (1970), and with higher loads occurring during periods of high flow. In 1965 (before the open pit) and in 1988, the increase in sulfate across the reach adjacent to the mine was approximately equal. In both 1992 and 1995, roughly 50% of the sulfate measured in the Red River above Questa could be attributed to the reach

adjacent to the Molycorp Mine. Potential sources of sulfate load along this reach may include either natural or mine-related flows.

5. The alkalinity measured in the Red River (Figure 5) provides an important indication of the balance of acidic and alkaline waters that have mixed together from various sources. Williams, and several literature sources (Slifer 1996) allege that acid rock drainage (ARD) from the Molycorp Mine causes an increase in metals in the Red River. If acidic water flows into a stream containing alkaline water, the stream will become less alkaline (or may even become acidic) downstream of the mixing zone. The ability of ARD to decrease stream alkalinity or to cause acidic stream chemistry has been demonstrated by a number of authors (Chapman and others 1983, Theobald and others 1962).

Alkalinity is an important aspect of overall water quality because the pH of water decreases in acidic water, the solubility of metals is increased in low pH water, metals tend to occur in a dissolved rather than in a total recoverable form at low pH which increases their bioavailability, and water quality standards for protection of aquatic life for several metals are higher in alkaline (high hardness) waters.

The total load of alkalinity (in g/s) within the Red River increases slightly in a downstream direction. Alkalinity loads have not changed between 1965 and the present. This indicates that if low pH waters are moving towards the Red River: 1) their contribution has not changed since 1965, before development of the open pit; 2) they are neutralized before they reach the river or within a mixing zone within the river; or 3) acidic flows constitute a minor proportion of the total inflow to the Red River.

There are few usable data for metal concentration and flow in the Red River available prior to development of the open pit. All metal loads described in this section were calculated for the total recoverable forms rather than the dissolved forms of metals. It should be noted that EPA recognizes that the many metals, especially zinc and aluminum, are more bioavailable in their dissolved than in the total recoverable form. In recent analyses of Red River water, all dissolved metal concentrations are below the EPA acute standards and are below or near the EPA chronic standards for protection of aquatic life. Chronic standards for dissolved aluminum were exceeded in the Red River above the mine and in the reach adjacent to the mine in 1992 and 1995, the only years with measurements for dissolved aluminum.

Total aluminum concentrations (Figure 6) tend to increase in a downstream direction and a significant increase in aluminum occurs over a 2 mile reach just upstream of the mine (probably from Hanson Creek), adjacent to the mine, and downgradient of the mine. Aluminum increases in the Red River upgradient of the mine confirms that there are aluminum loads that are attributable to natural sources. At the pH observed in the Red River, most aluminum would be expected to occur in the form of small ("colloidal") particles of aluminum oxyhydroxide, with low levels of dissolved aluminum (Woodward Clyde 1996).

6. Total iron loads (Figure 7) do not change appreciably throughout the length of the Red River except during the highest measured flow (October, 1988 – 30 cfs). Chemical precipitates (composed of iron and aluminum oxyhydroxides) that have lodged in the stream bed gravels can be re-suspended during periods of high flow. During such high flows, this re-suspension of precipitates that previously settled out of the water can lead to the mistaken conclusion that surface water flows or seeps are contributing significant iron loads. At the pH observed in the Red River, all iron would be expected in the form of small ("colloidal") particles of iron oxyhydroxide, with no measurable dissolved iron (Woodward Clyde 1996).

7. The primary source of total manganese loads (Figure 8) in the Red River occurred downgradient of the mine in 1988 and 1992, while the reach adjacent to the mine received significant increases in load in 1995. Potential sources of manganese include natural hydrothermal scars or mine sources as discussed for TDS and sulfate loads.

8. The changes in zinc loading (Figure 9) were very similar to those for manganese and similar conclusions can be drawn about potential sources.

4.3 Geochemical Signatures of Potential Sources of Mass Load

1. Flow in the Red River comes from a number of sources that may differ geochemically (Table 1). In general, these potential sources can be classified as surface or groundwater contribution from unmineralized portions of the basin, surface or groundwater flow from natural hydrothermal scar areas, and surface or groundwater flow from mine waste rock sources.

2. Williams argues that the concentrations of metals and sulfate in water contacting mine waste rock and soils from hydrothermal scars provides a means of distinguishing between the two sources. Williams indicated that mine water in contact with mine waste rock has higher levels of manganese and zinc than water from hydrothermal scars. This observation was based upon comparison of standing water and runoff from 9 samples of waste rock and 8 samples of hydrothermal scar water (SRK 1995). The average composition of each group of samples was compared to see which had a higher metal concentration. While the waste rock samples had higher average concentrations of manganese, zinc and other metals, the variability of individual measurements within each group were large.

   I used a statistical test to determine whether the average metal concentrations for the two groups of samples was significantly different. A non-parametric analysis of variance was used for this test (Table 2). The apparent differences in average metal contents were not significantly different at a probability of 95%.

   Additional data were collected to assess any potential differences between water contacting hydrothermal scars and mine waste rock. Shaker flask tests for grab samples of scar and waste rock were obtained from SRK (1995). The mean metal concentrations from these two sets of samples were compared and the apparent difference in the mean metal concentration was used by SRK to support the theory that some metals, especially zinc and manganese are higher in water contacting mine rock. The same statistical test was used to determine whether the average metal concentrations for the two groups of shaker tests was significantly different. The non-parametric analysis of variance showed that the apparent differences in average metal contents were not significantly different at a probability of 95% (Table 3).

Slifer (1996) compared the average total metal concentration in 4 scar samples and in 7 waste rock samples. Based on the apparent differences in the average total metal concentration, Slifer concluded that waste rock had higher total concentrations of manganese and zinc. A non-parametric analysis of variance (Table 4) indicates that the scar and waste rock samples are not significantly different in total aluminum, manganese or zinc. The hydrothermal scar samples are higher in total iron. In water contacting sediment or rock material, the concentration of the metals (iron, aluminum, manganese, and zinc) is not strongly affected by total metal content. Therefore, even if scar and waste rock samples had differed in total metals, this cannot be used to infer that water contacting these materials would differ in metal concentration.

3. All available geochemical data from scar and mine rock shaker tests, and surface water in contact with scars or mine rock, were combined with the observed chemistry of seeps, and the Red River on solubility diagrams (Figure 11 through 15). Analyses of the data from all sources indicates that the pH of the samples is the primary factor that controls the metal concentration. Metal levels are highest at low pH in water in contact with waste rock or scars; in seeps; or in the Red River. Samples of waste rock and scars had wide range of pH and metal levels from each of these sources showed significant overlap due to the range in observed pH. Differences in the concentration of zinc and manganese in water contacting waste rock or scars, even if statistically significant, would not cause water from waste rock to have higher zinc or manganese levels if it reached the Red River. Samples collected by SRK were waters in direct

contact with waste rock or scar material, and thus are representative of surface runoff. Surface water from waste rock piles that is alleged to impact the Red River would infiltrate through the waste rock, continue to migrate downward in natural sediments until it mixed with the local groundwater system. After mixing, the seepage could potentially migrate downgradient until in entered the Red River. Bedrock units near the Molycorp mine, especially andesite and aplite, contains a significant amount of carbonate material. As acidic water travels through such bedrock or alluvial sediments a number of chemical reactions occur that tend to slow the rate of travel of some constituents (especially acidity, aluminum and iron) while barely affecting the rate of flow of other constituents (like TDS). As a result, aluminum, iron and acidity that may exit a waste rock pile would not be expected to travel quickly through underlying bedrock or alluvium. The capacity of bedrock or alluvial materials to attenuate metals and acidity will be exhausted only after a great number of decades or centuries so that all constituents including metals can travel at an equal rate. Therefore, the rate of travel of metals leached from hydrothermal scars (which have existed for millennia) would be expected to be faster than from waste rock areas. Consequently, differences in the chemistry of water in contact with waste rock versus scar material do not indicate that seepage fed from these sources can be reliably distinguished based on subtle differences in metal concentration measured in the Red River.

4. Figures 11, 12 and 13 illustrate the concentrations of sulfate, aluminum and iron in the Red River, in seeps, and in waters in contact with natural scar material and with mine rock. In addition, a geochemical model (Phreeqc, Parkhurst 1995) was used to calculate the theoretical concentration of these constituents that would occur in equilibrium with particular minerals. Sulfate concentration in acidic seeps and waters contacting scars and mine rock indicate that gypsum may be present. Gypsum is not in equilibrium with Red River water since measured sulfate levels are much lower than the gypsum solubility curve. Aluminum and iron minerals (boehmite and amorphous ferrihydrite) appear to control the solubility of iron and aluminum in seeps, waters

contacting scars and mine rock, and in the Red River. This fact indicates that the pH of the surface and groundwater system determines the resulting aluminum and iron concentration. Consequently, apparent changes in dissolved aluminum and iron levels in either surface or groundwater can not identify the waste rock piles as a source of these metals. The solubility of manganese and zinc was not modeled in Phreeqc. The solubility of manganese is strongly affected by the degree of oxidation (the redox potential) and solubility varies widely over the range of redox conditions commonly observed in surface water and shallow groundwater at the Questa mine site. The solubility of zinc was not modeled because willemite, a zinc silicate, is often the least soluble mineral in natural waters. In order to predict the concentration of zinc in water in contact with willemite, the pH and dissolved silica concentrations must be known and no data are available for the dissolved silica concentration.

4.4 Determining the Contributions of Acidic Inflows to the Red River

1. The change in flow and surface chemistry in the reach of Red River adjacent to the Molycorp mine can be used to back-calculate the average chemistry of influent water. Reports from Williams, Mink, and Kelsey contend that most of the water flowing into the Red River from this reach is mine-affected. Additionally, the reports argue that the mine-affected water is acidic and contains highly elevated levels of metals.

2. I used data from 1965, 1988, 1992 and 1995 to calculate the average characteristics of water inflows to the Red River adjacent to the mine (Table 5). The average pH of inflow water is near-neutral and the average inflow is moderately alkaline. Consequently, it is clear that the water flowing into the Red River in this reach is not strongly acidic. The inflow which averages 3.7 cfs is probably a mixture of alkaline and low TDS groundwater, and a small proportion of acidic water, which may explain the average total aluminum, iron, manganese and zinc calculated for water flowing into this reach. Based on proportional weighted averaging of the influent chemistry with typical acidic and non-acidic waters, acidic

water represents less than 10% of the total flow into the Red River along this reach. Natural hydrothermal scars occurring along this reach could easily contribute this amount of flow (0.37 cfs or 166 gpm). At a typical groundwater recharge rate of 0.25 feet/year, only 66 acres of scar areas would be needed to contribute this amount of flow. There are 160 acres of undisturbed hydrothermal scars in the basin along this reach of the Red River based on maps produced by SRK (1995).

3. Phreeqc (Parkhurst 1995) was used to investigate the potential contribution of acidic water to the Red River. Data from the 1995 surface water sampling (Woodward Clyde 1996) were used for this model because complete ion analyses were completed on these samples. Water sampled at the mouth of Hanson Creek and water flowing at Cabin Springs were each used as "typical" acidic waters. Hanson Creek is a natural acidic source while Cabin Springs may be either natural or mine-affected. A water sample from Red River upgradient of the town of Red River was used to represent natural runoff or seepage unaffected by either scar areas or the mine. Acid water and unaffected river water were mixed in varying percentages, and the resulting zinc and sulfate levels were compared to downgradient Red River water. The resulting graphs can be graphically interpreted to show that acidic seepage represents only 2 to 4.5% of the total flow in the Red River basin, or 0.6 to 1.35 cfs at an average flow of 30 cfs. This amount of flow would be contributed from an "acidic" area of 108 to 244 acres with an average groundwater recharge of 0.25 feet/year. The area of the basin covered by hydrothermal scars is much larger than this area, and likely accounts for the loading observed in the Red River both before and after mining.

4.5 Chemical Dynamics in Surface Waters Impacted by Acidic Seeps

1. Most available data used to calculate mass loads were collected during "baseflow" periods. Baseflow refers to the time when the majority of water in a stream is contributed by groundwater inflows, as opposed to the runoff period when most flow is contributed by surface runoff. Peak runoff rates occur in the Red River (Figure 10) during snowmelt or in

response to summer thunderstorms.

Large increases in mass load can occur during runoff periods, especially if the flow regime is great enough to scour the streambed and remove precipitated metals that have accumulated in the bed. Mass load and flow at the Ranger Station were measured by Smolka and Tague (1989) four times after a September, 1988 rainstorm event. As flow decreased from 140 to 30 cfs, sulfate loads decreased by 4 to 5 times. Loads of iron, manganese and zinc decreased 10 times, and aluminum loads decreased 100 times. In many streams that are biologically impaired due to metals input, the impact occurs during high flow periods when metals are flushed into the river or when precipitates are re-suspended. Fish kills on the Clark Fork River in Montana have been described after large summer thunderstorms. In 1988, Bitter Creek (4 miles above the mine) was the only station that exceeded EPA aquatic life standards for metals (Smolka and Tague 1989). If biological impairment occurs mostly due to runoff of acidic water during high flow conditions, then the impairment cannot be attributed to the mine, because surface runoff from mine facilities does not reach the Red River.

2. Changes in the mass load or concentration of constituents in water in a downstream direction (or through time) is often used a means of identifying potential sources of input (such as from a mine). Williams relied on a comparison of concentrations in the Red River measured in 1965 and in 1988 to conclude that the mine had caused an increase in loading. Other referenced reports including Slifer (1995), similarly rely on analysis of concentrations in the Red River as a means of assessing load increases.

3. A mass load model implicitly assumes that the constituents analyzed are "conservative", meaning that they are not stored at any point within the system. Similarly, flux between surface water and alluvial groundwater can complicate the analysis of mass load data. Some constituents such as TDS are chemically conservative. However, most metals, and especially iron and aluminum, often are not conservative.

4. In 1962 Theobald and others described the mixing of an acidic and an alkaline stream in Colorado. After mixing, a number of metals including iron, aluminum, and manganese were removed from the surface water system and were deposited as a sediment layer on the streambed. Large quantities of other metals were removed from solutions. Iron and manganese oxyhydroxides are well known for their ability to adsorb a wide variety of metals and scavenge them from solution. Johnson (1986) described the adsorption of copper and zinc on iron oxyhydroxides in the Carnon River in England. Chapman and others (1983) and Chapman (1982) developed models to predict the transport of metals in natural waters comprised of mixtures of acidic and alkaline water. The model describes the complex interaction of dissolved metals, bed sediments, and suspended metals in streams. Runkel and others (1996) and Bencala and others (1990) describe the transport of metals in streams affected by input of acidic water. Metals moved more slowly than predicted due to interaction with bed sediments.

All of the research cited above describe a number of complex processes that affect metal transport. Based on these studies, changes in metal concentrations within a river system can be attributed to a number of factors including deposition in the streambed, resuspension of previously deposited precipitates, adsorption onto bed sediments or dissolution from bed sediments. Consequently, changes in concentration in metals in the Red River cannot be reliably attributed to the Molycorp mine without proper consideration of these processes. When surface water data are properly interpreted, there is no indication that the Molycorp Mine currently or at any time has contributed metal loads to the Red River.

5. References Cited

Bencala, B.E. and D. McKnight, G Zellweger. 1990. Characterization of transport in an acidic and metal-rich mountain stream based on a lithium tracer injection and simulations of transient storage. Water Resources Research, Vol. 26(5):989-1000.

Chapman, B.M. 1982. Numerical simulation of the transport and speciation of nonconservative chemical reactants in rivers. Water Resources Research, Vol. 18(1):155-167.

Chapman, B.M., D.R. Jones and R.F. Jung. 1983. Processes controlling metal ion attenuation in acid mine drainage waters. Geochemica Cosmochimica Acta. Vol. 32:419-430.

Chapman, B.M., D.R. Jones and R.F. Jung. 1983. Geochemica Cosmochimica Acta. Vol. 47, pp. 1957-1973. Pergamon, Ltd.

Dunne, T and L.B. Leopold. 1978. Water in Environmental Planning. W.H. Freeman and Company, San Francisco. 818 pgs.

Johnson, C.A. 1986. The regulation of trace element concentrations in river and estuarine waters contaminated with acid mine drainage: the adsorption of Cu and Zn on amorphous Fe oxyhydroxides. Geochemica Cosmochimica Acta. Vol. 50:2433-2438. Pergamon, Ltd.

Mau, D.P. and T.C. Winter. 1997. Estimating groundwater recharge from streamflow hydrographs for a small mountain watershed in a temperate humid climate, New Hampshire, USA. Ground Water 35(2):291-304

Parkhurst, D.L. 1995. Users Guide To Phreeqc – A Computer Program For Speciation, Reaction-Path, Advective Transport, And Inverse Geochemical Reactions. US Geological Survey. Water Res. Inv. Rpt 95-4227. Lakewood, CO

Runkel, R.L. 1996. Reactive solute transport in streams - 2. Simulation of a pH modification experiment. Water Resources Research. Vol. 32: 419-430.

Slifer, D. 1996. Red River Groundwater Investigation. New Mexico Environment Department submitted to US EPA – Region VI.

Smolka, L.R. and D.F. Tague. 1988. Intensive Water Quality Survey of the Middle Red River, Taos County, New Mexico. New Mexico Health and Environment Department.

Steffen Robertson and Kirsten. 1995. Questa Molybdenum Mine Geochemical Assessment and Preliminary Closure Plan. Report to Molycorp.

Theobald, P.K. Jr., H.W. Lakin and D.B. Hawkinst. 1962. The precipitation of aluminum, iron and manganese at the junction of Deer Creek with the Snake River in Summit County, CO. Geochemica Cosmochimica Acta. Vol. 27, No. 2, pp. 121-132.

US Environmental Protection Agency. 1971. A Water Quality Survey – Red River and Rio Grande – New Mexico. Surveillance and Analysis Division. Ada, OK

US Geologic Survey. 1997. Water Resources Information – Red River near Questa, NM (Station 08265000). http://h2o.usgs.gov/NM/?statnum=08265000

Vail Engineering. 1993. Interim Study of the Acidic Drainage to the Middle Red River Taos County, New Mexico. Report submitted to Molycorp.

Water Pollution Control Administration. 1966. A Water Quality Survey – Red River of the Rio Grande - New Mexico. Robert S. Kerr Water Research Center. Ada, OK

Woodward-Clyde. 1996. Draft Red River Water Investigation Report – November 1995 – Molycorp Questa Mine. Report to Molycorp.

Table 1. Chemical characteristics of potential sources of flow to the Red River.

Inflow source	Surface or Groundwater	Chemical characteristics
Unmineralized areas	Surface water	neutral pH, alkaline, low TDS water similar to Columbine Creek (Woodward Clyde 1995)
	Groundwater	neutral pH, alkaline, low to moderate TDS water represented by baseflow above Red River
Hydrothermal scars	Surface water	variable pH, sulfate, TDS and metals presented by samples in Table 2.1 (SRK 1994)
	Groundwater	represented by background seep sample __ in SRK (1994), but pH, sulfate, TDS and metals are widely variable
Molycorp mine	Surface water	Surface runoff controlled by mine.
	Groundwater	groundwater contributions adjacent to the Red River may be affected by the mine or by hydrothermal scars. Existing data do not differentiate between these sources

Table 2. Analysis of variance for surface water in contact with hydrothermal scars and with mine rock (data from SRK 1995).

Comparison of Dissolved Metals in Water Contacting Hydrothermal Scars (Type = 1) and Mine Rock (Type = 2)

Reference SRK (1995)

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
AL_MGPKG	11	7184.5455	4786.2352	1910.00	18900.00
FE_MGPKG	11	41948.18	41046.46	7830.00	156000.0
MN_MGPKG	11	318.9273	289.7890	17.70	1080.00
ZN_MGPKG	11	92.1182	159.4162	20.80	569.00
SITETYPE	11	1.3636	.5045	1.00	2.00

Kruskal-Wallis Tests

Ranks

	SITETYPE	N	Mean Rank
AL_MGPKG	1.00	7	5.57
	2.00	4	6.75
	Total	11	
FE_MGPKG	1.00	7	4.29
	2.00	4	9.00
	Total	11	
MN_MGPKG	1.00	7	7.14
	2.00	4	4.00
	Total	11	
ZN_MGPKG	1.00	7	7.00
	2.00	4	4.25
	Total	11	

Test Statistics[a,b]

	AL_MGPKG	FE_MGPKG	MN_MGPKG	ZN_MGPKG
Chi-Square	.321	5.143	2.286	1.750
df	1	1	1	1
Asymp. Sig.	.571	.023	.131	.186

a. Kruskal Wallis Test

b. Grouping Variable: SITETYPE

Mann Whitney Tests

Ranks

	SITETYPE	N	Mean Rank	Sum of Ranks
AL_MGPKG	1.00	7	5.57	39.00
	2.00	4	6.75	27.00
	Total	11		
FE_MGPKG	1.00	7	4.29	30.00
	2.00	4	9.00	36.00
	Total	11		
MN_MGPKG	1.00	7	7.14	50.00
	2.00	4	4.00	16.00
	Total	11		
ZN_MGPKG	1.00	7	7.00	49.00
	2.00	4	4.25	17.00
	Total	11		

Test Statistics[b]

	AL_MGPKG	FE_MGPKG	MN_MGPKG	ZN_MGPKG
Mann-Whitney U	11.000	2.000	6.000	7.000
Wilcoxon W	39.000	30.000	16.000	17.000
Z	-.567	-2.268	-1.512	-1.323
Asymp. Sig. (2-tailed)	.571	.023	.131	.186
Exact Sig. [2*(1-tailed Sig.)]	.648[a]	.024[a]	.164[a]	.230[a]

a. Not corrected for ties.

b. Grouping Variable: SITETYPE

Table 3. Analysis of variance for shaker test data for samples of material from hydrothermal scars and mine rock (data from SRK 1995).

Comparison of Dissolved Metals in Shaker tests of Samples from Hydrothermal Scars (Type = 1) and Mine Rock (Type = 2)

Reference SRK (1995)

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
ALUMINUM	23	17.16261	33.91286	.02000	133.0000
H_ION	48	2.7E-04	5.7E-04	0.0E+00	2.3E-03
IRON	22	12.08318	46.95729	.03000	221.0000
MANGANESE	23	3.100043	5.814834	.00600	20.90000
SULFATE	10	914.7100	790.9921	68.10000	2830.000
TDS	47	564.2553	613.1024	10.00000	2000.000
ZINC	23	.4275217	.8166208	.00500	3.26000
TYPE	48	1.583333	.4982238	1.00000	2.00000

Kruskal-Wallis Tests

Ranks

	TYPE	N	Mean Rank	Sum of Ranks
ALUMINUM	1.00000	11	10.23	112.50
	2.00000	12	13.63	163.50
	Total	23		
H_ION	1.00000	20	27.15	543.00
	2.00000	28	22.61	633.00
	Total	48		
IRON	1.00000	11	10.73	118.00
	2.00000	11	12.27	135.00
	Total	22		
MANGANESE	1.00000	11	10.09	111.00
	2.00000	12	13.75	165.00
	Total	23		
SULFATE	1.00000	1	2.00	2.00
	2.00000	9	5.89	53.00
	Total	10		
TDS	1.00000	20	19.27	385.50
	2.00000	27	27.50	742.50
	Total	47		
ZINC	1.00000	11	11.36	125.00
	2.00000	12	12.58	151.00
	Total	23		

Test Statistics[a,b]

	ALUMINUM	H_ION	IRON	MANGANESE	SULFATE	TDS	ZINC
Chi-Square	1.466	1.235	.315	1.671	1.485	4.140	.186
df	1	1	1	1	1	1	1
Asymp. Sig.	.226	.266	.575	.196	.223	.042	.666

a. Kruskal Wallis Test

b. *Grouping Variable:* TYPE

Mann Whitney Tests

Ranks

	TYPE	N	Mean Rank
ALUMINUM	1.00000	11	10.23
	2.00000	12	13.63
	Total	23	
H_ION	1.00000	20	27.15
	2.00000	28	22.61
	Total	48	
IRON	1.00000	11	10.73
	2.00000	11	12.27
	Total	22	
MANGANESE	1.00000	11	10.09
	2.00000	12	13.75
	Total	23	
SULFATE	1.00000	1	2.00
	2.00000	9	5.89
	Total	10	
TDS	1.00000	20	19.27
	2.00000	27	27.50
	Total	47	
ZINC	1.00000	11	11.36
	2.00000	12	12.58
	Total	23	

Test Statistics[b]

	ALUMINUM	H_ION	IRON	MANGANESE	SULFATE	TDS	ZINC
Mann-Whitney U	46.500	227.000	52.000	45.000	1.000	175.500	59.000
Wilcoxon W	112.500	633.000	118.000	111.000	2.000	385.500	125.000
Z	-1.211	-1.111	-.561	-1.293	-1.219	-2.035	-.431
Asymp. Sig. (2-tailed)	.226	.266	.575	.196	.223	.042	.666
Exact Sig. [2*(1-tailed Sig.)]	.235[a]		.606[a]	.211[a]	.400[a]		.695[a]

a. Not corrected for ties.

b. *Grouping Variable: TYPE*

Table 4. Analysis of variance for total metals in samples of hydrothermal scars and mine rock (data from Slifer 1996).

Non Parametric Tests

Comparison of Total Metals in Hydrothermal Scars (Type = 1) and in Mine Rock (Type = 2)

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
ACIDITY	17	3001.412	3779.753	326.00	12200.00
ALUMINUM	17	349.12	495.72	4	1850
EC	17	4547.65	3213.87	1350	12300
IRON	17	227.24	305.93	1	836
MANGANESE	17	124.53	223.81	2	777
SULFATE	17	3747.12	3443.09	735	12700
ZINC	17	22.00	40.89	0	130
TYPE	17	1.53	.51	1	2

Reference Slifer (1995)

Kruskal-Wallis Tests

Ranks

	TYPE	N	Mean Rank	Sum of Ranks
ACIDITY	1	8	9.38	75.00
	2	9	8.67	78.00
	Total	17		
ALUMINUM	1	8	8.88	71.00
	2	9	9.11	82.00
	Total	17		
EC	1	8	9.00	72.00
	2	9	9.00	81.00
	Total	17		
IRON	1	8	10.44	83.50
	2	9	7.72	69.50
	Total	17		
MANGANESE	1	8	7.19	57.50
	2	9	10.61	95.50
	Total	17		
SULFATE	1	8	8.75	70.00
	2	9	9.22	83.00
	Total	17		
ZINC	1	8	7.94	63.50
	2	9	9.94	89.50
	Total	17		

Test Statistics[a,b]

	ACIDITY	ALUMINUM	EC	IRON	MANGANESE	SULFATE	ZINC
Chi-Square	.083	.009	.000	1.226	1.952	.037	.678
df	1	1	1	1	1	1	1
Asymp. Sig.	.773	.923	1.000	.268	.162	.847	.410

a. Kruskal Wallis Test

b. Grouping Variable: TYPE

Mann Whitney Tests

Ranks

	TYPE	N	Mean Rank
ACIDITY	1	8	9.38
	2	9	8.67
	Total	17	
ALUMINUM	1	8	8.88
	2	9	9.11
	Total	17	
EC	1	8	9.00
	2	9	9.00
	Total	17	
IRON	1	8	10.44
	2	9	7.72
	Total	17	
MANGANESE	1	8	7.19
	2	9	10.61
	Total	17	
SULFATE	1	8	8.75
	2	9	9.22
	Total	17	
ZINC	1	8	7.94
	2	9	9.94
	Total	17	

Table 5. Calculated flow rate and chemistry of inflow to the Red River for the reach adjacent to the Molycorp mine.

Date	Flow[1]	pH	Alkalinity
	Cfs	SU	(mg/L)
Nov, 1965	9.3	7.88	45.7
Nov, 1965	4.3	7.67	18.4
Nov, 1970	-1.5	7.00	96.3
Oct, 1988	4.0	6.55	-81.5
Oct, 1992	3.2	6.59	88.1
Nov, 1995	3.1	6.94	-58.2
Average[2]	3.7	6.94	-8.3

Notes to Table

1 – The average inflow chemistry was computed for 1965 assuming no flow in Columbine Creek and 5 cfs of flow. The calculated chemistry in 1970 represents the average water flowing out of the Red River, since in this year it was a losing reach.

2 – The average composition is based on 1965, 1988, 1992, and 1995 data. The data from 1970 were not used because the Red River was a losing reach in that year.

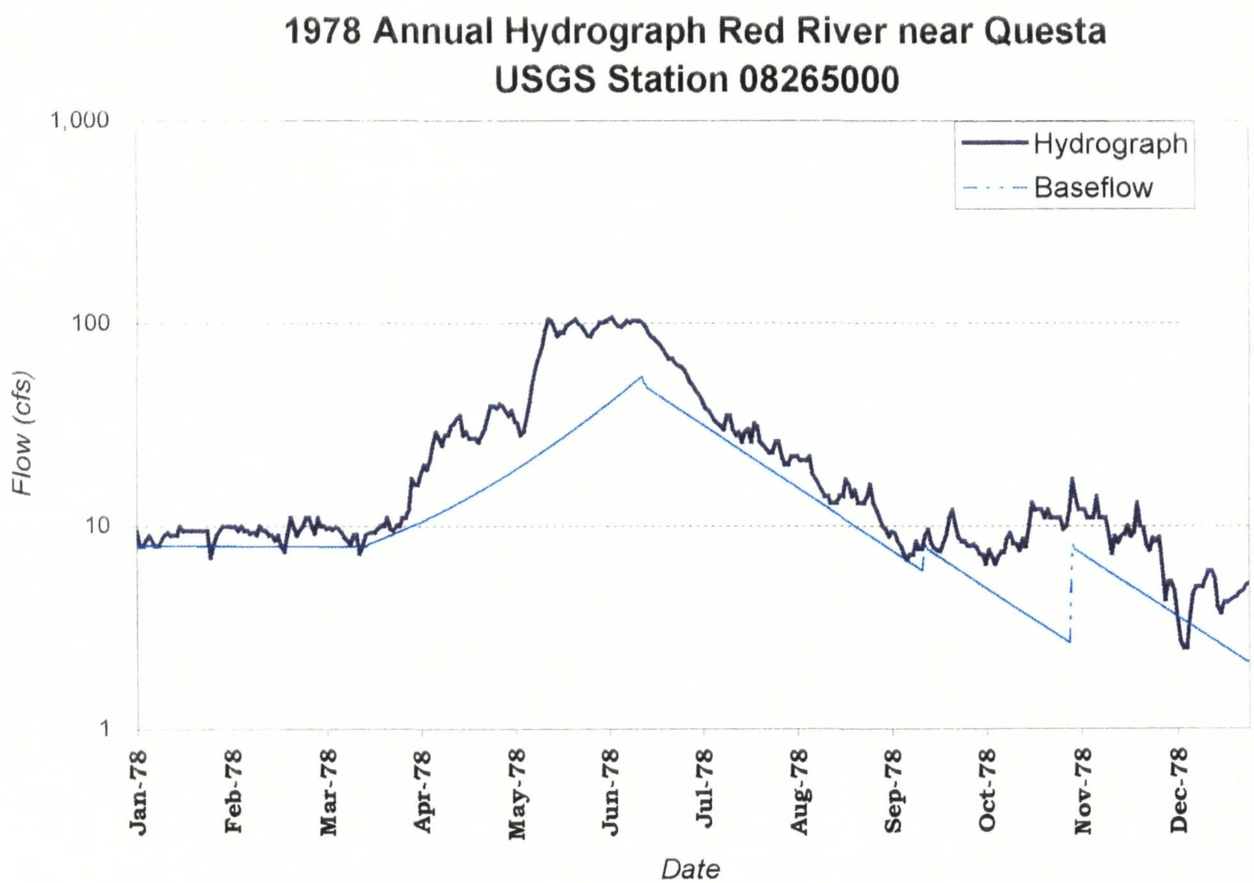


Figure 1. Hydrograph and estimated baseflow for the Red River near Questa in 1978.

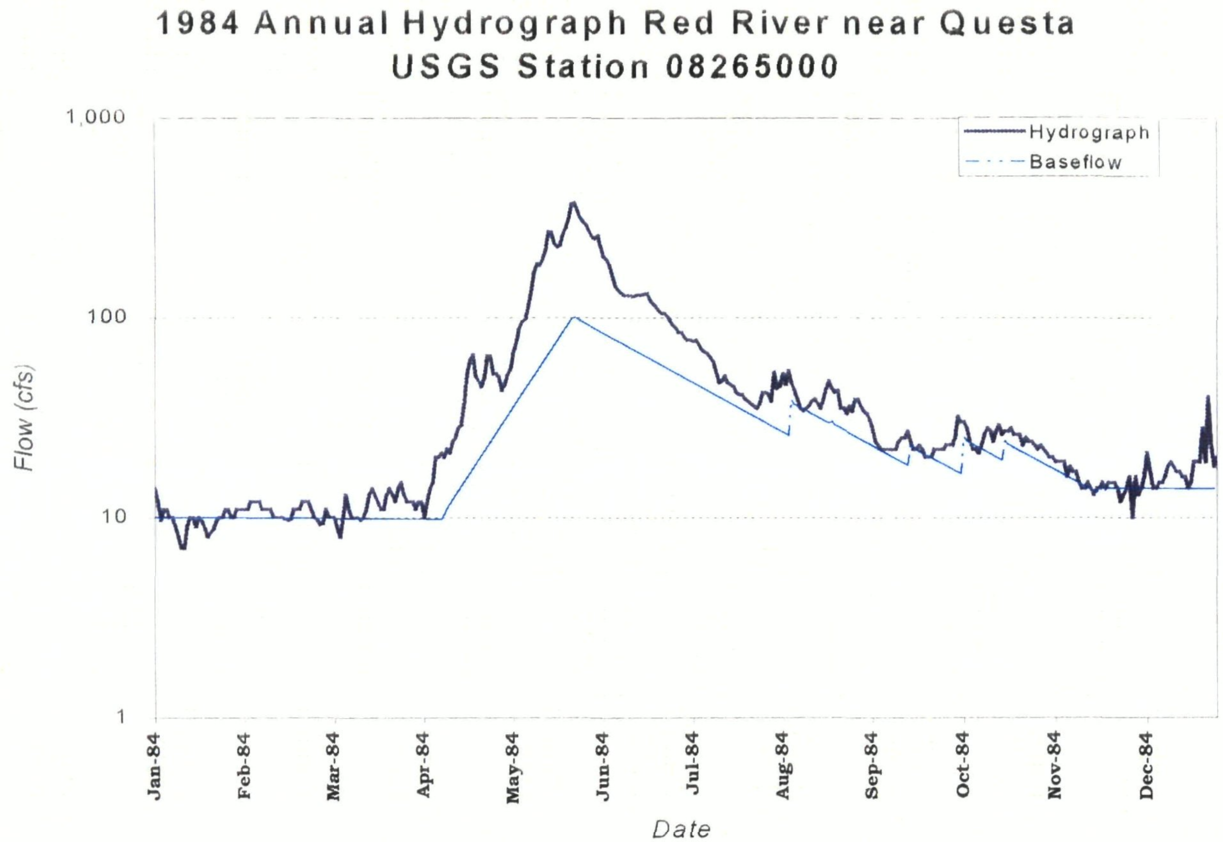


Figure 2. Hydrograph and estimated baseflow for the Red River near Questa in 1984.

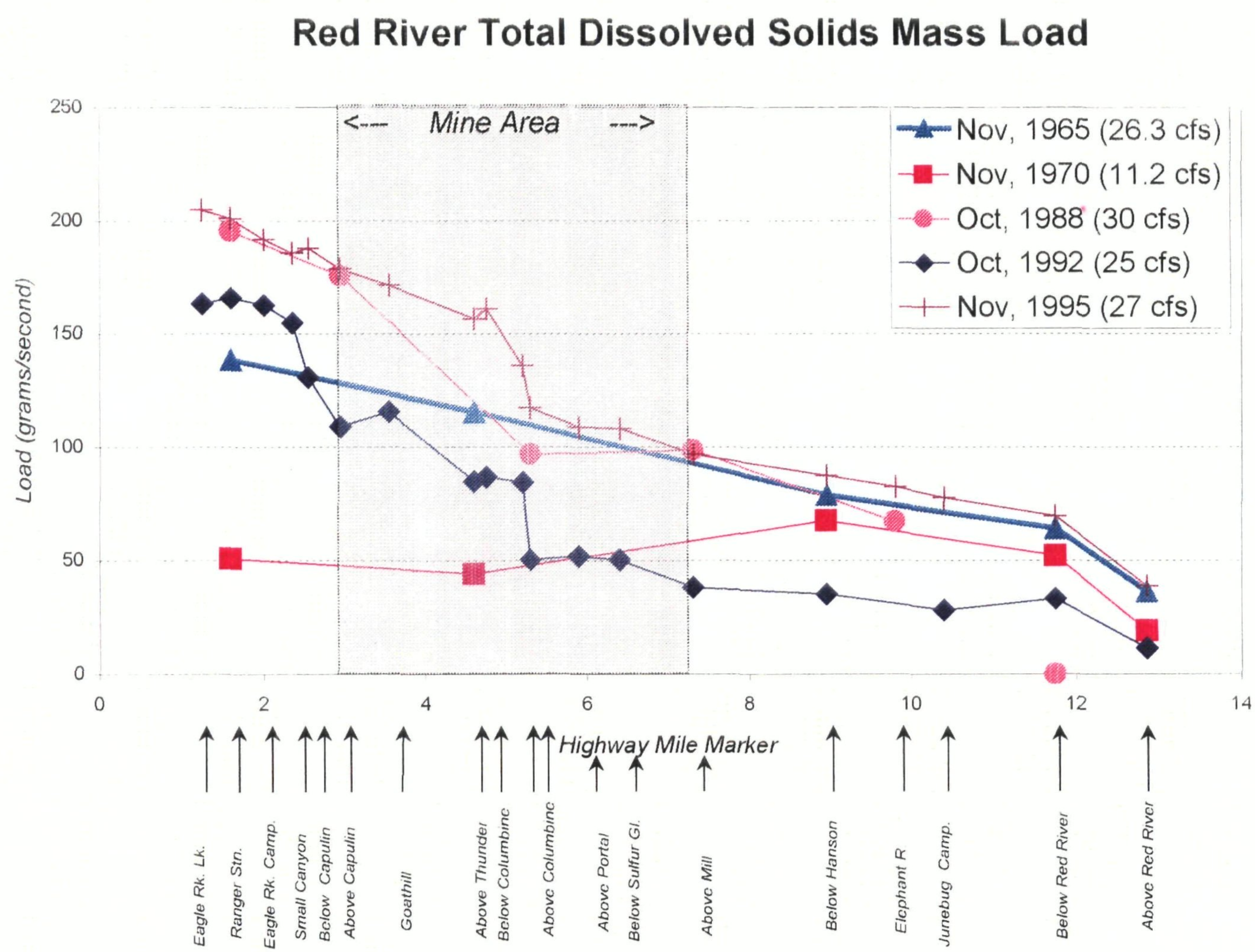


Figure 3a. Total Dissolved Solid (TDS) mass load in the Red River for several dates of measurement (1965 to 1995).

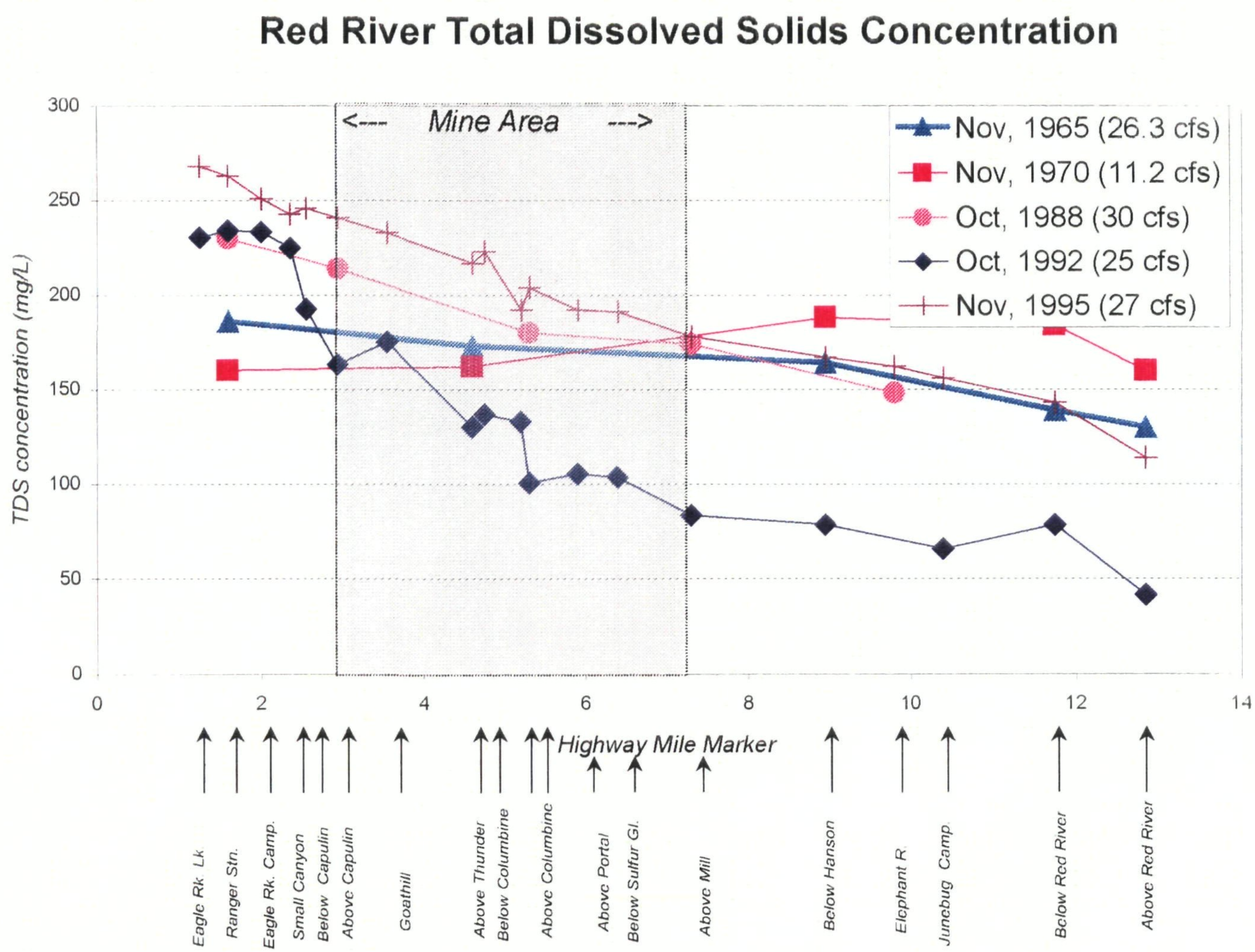


Figure 3b. Total Dissolved Solid (TDS) concentration in the Red River for several dates of measurement (1965 to 1995).

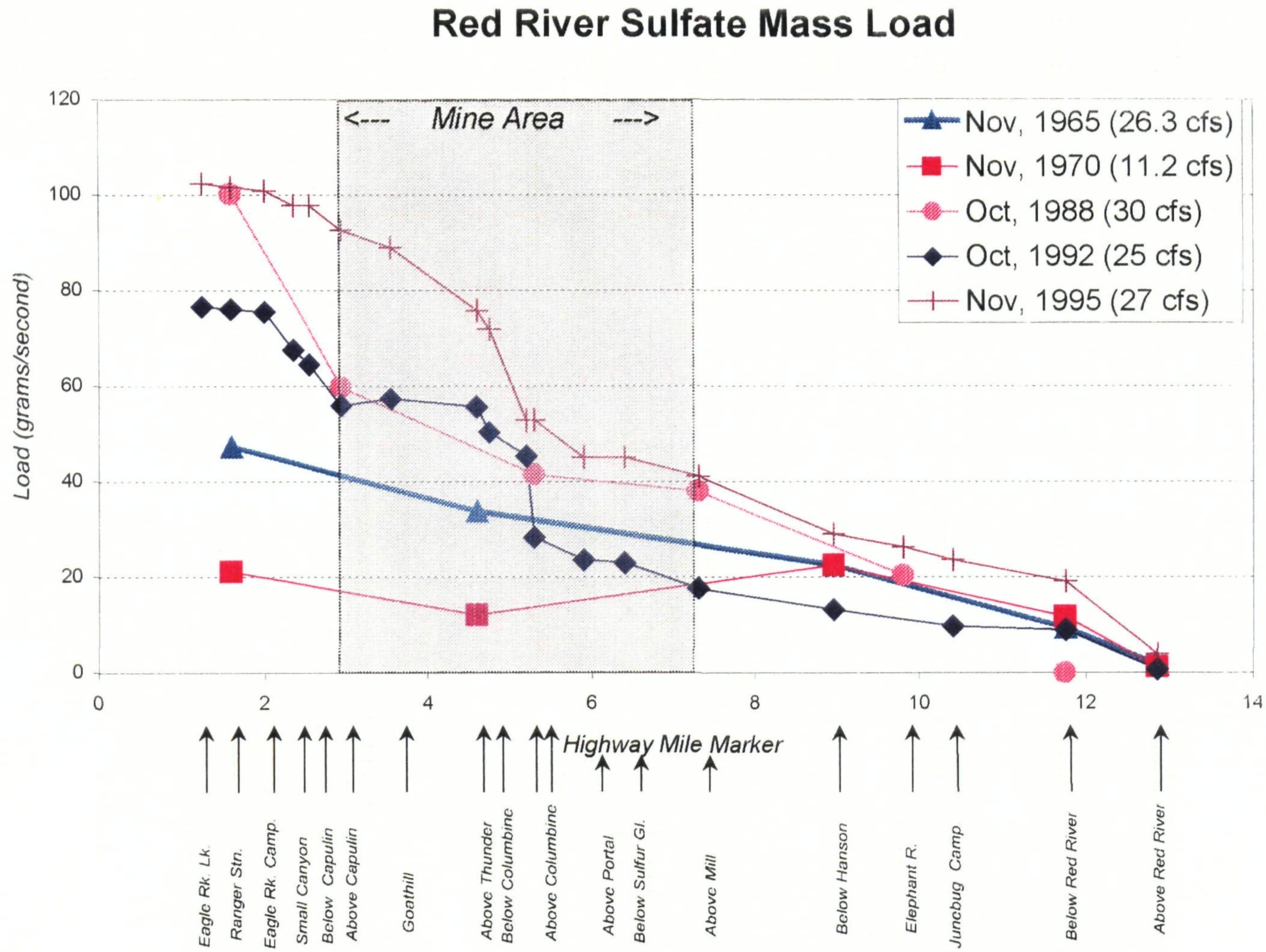


Figure 4. Sulfate mass load in the Red River for several dates of measurement (1965 to 1995).

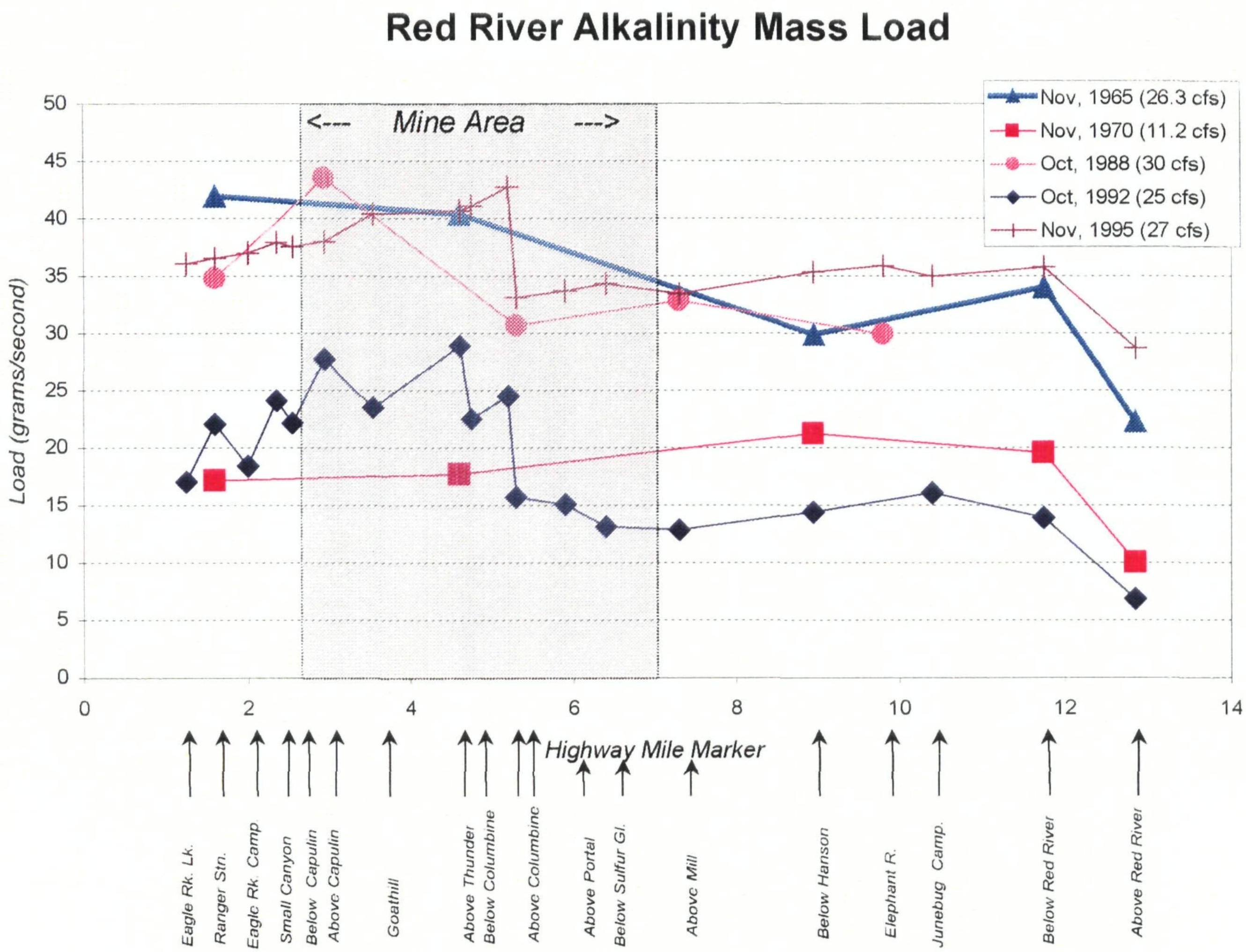


Figure 5. Alkalinity mass load in the Red River for several dates of measurement (1965 to 1995).

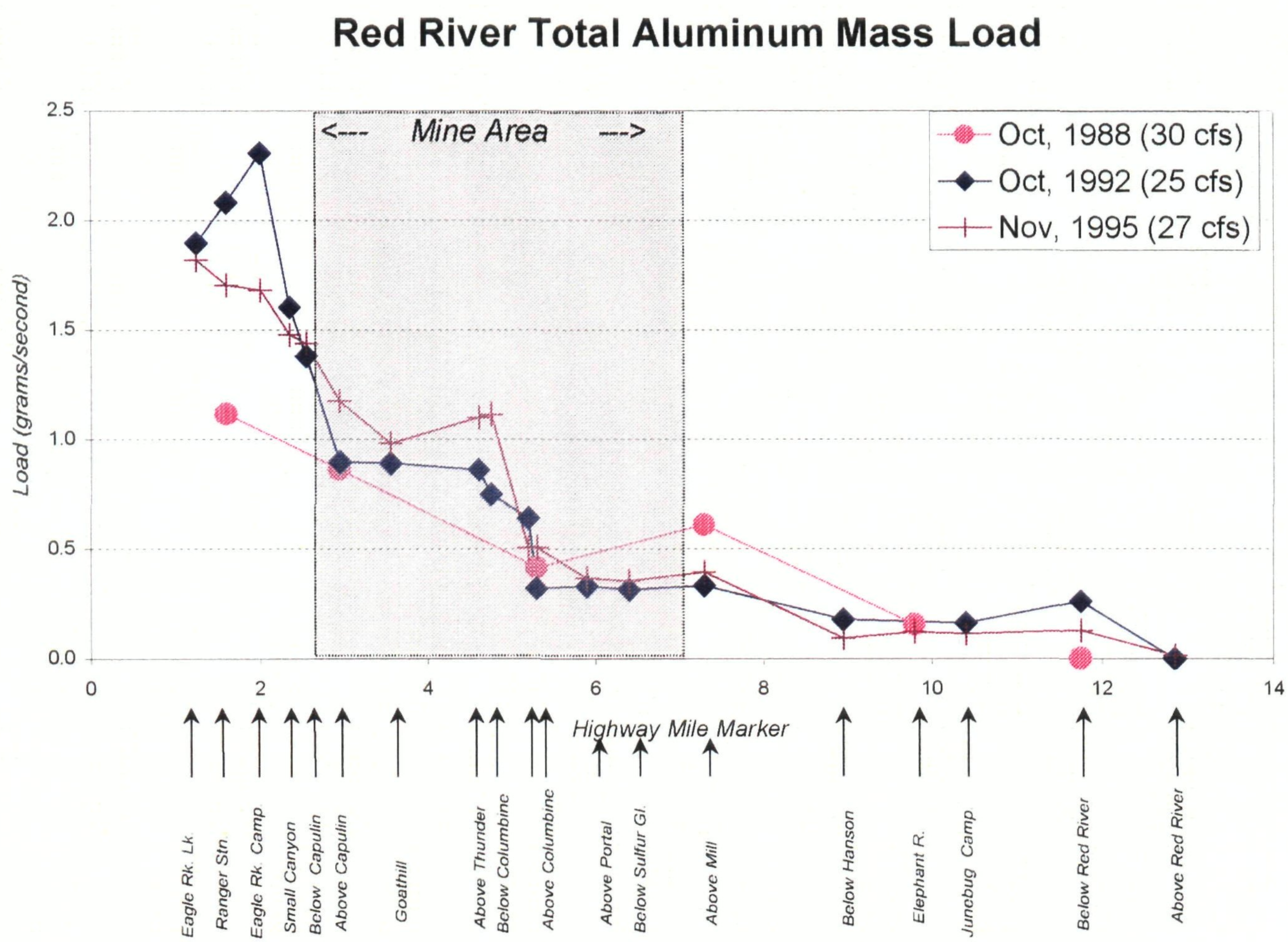


Figure 6. Aluminum mass load in the Red River for several dates of measurement (1965 to 1995).

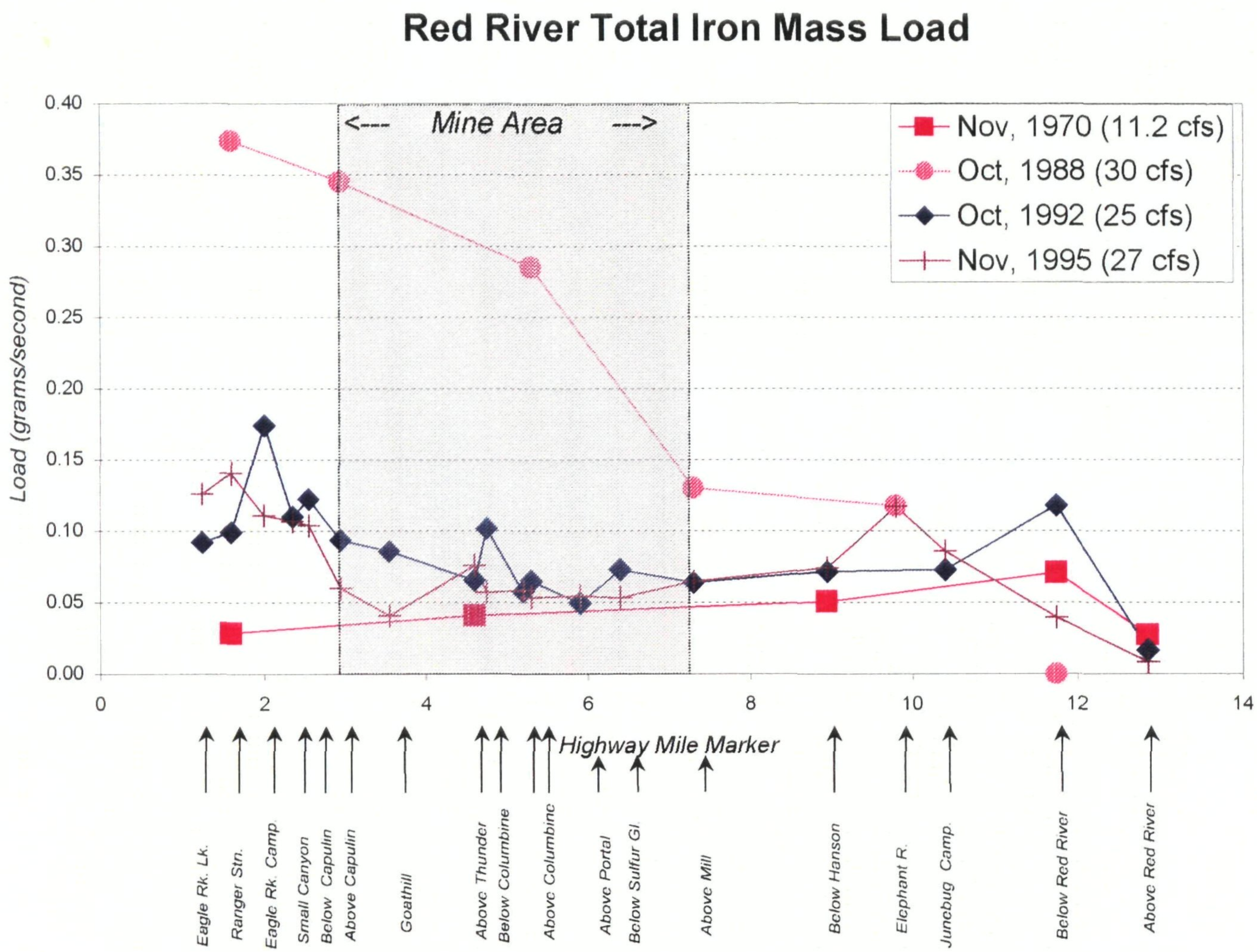


Figure 7. Iron mass load in the Red River for several dates of measurement (1965 to 1995).

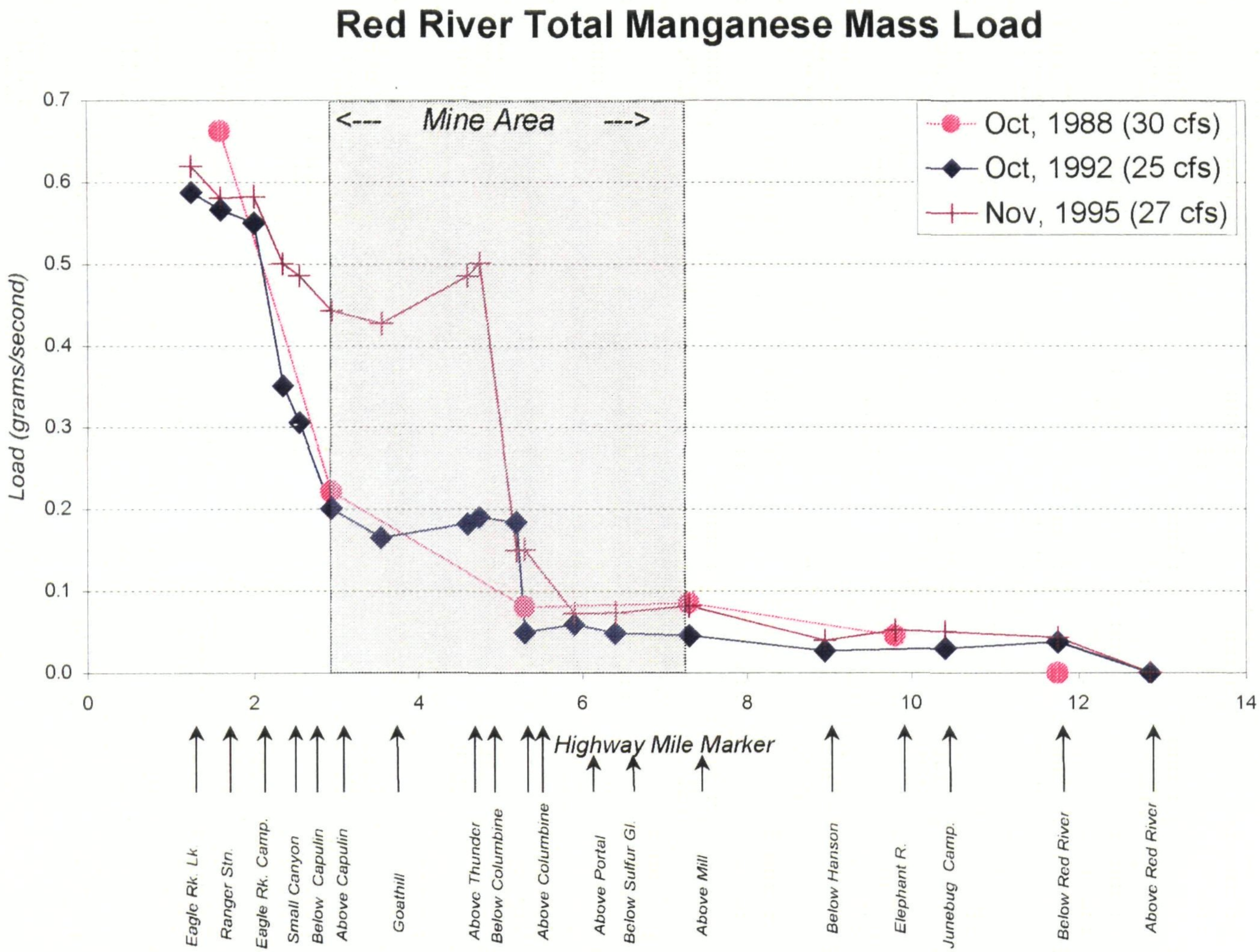


Figure 8. Manganese mass load in the Red River for several dates of measurement (1965 to 1995).

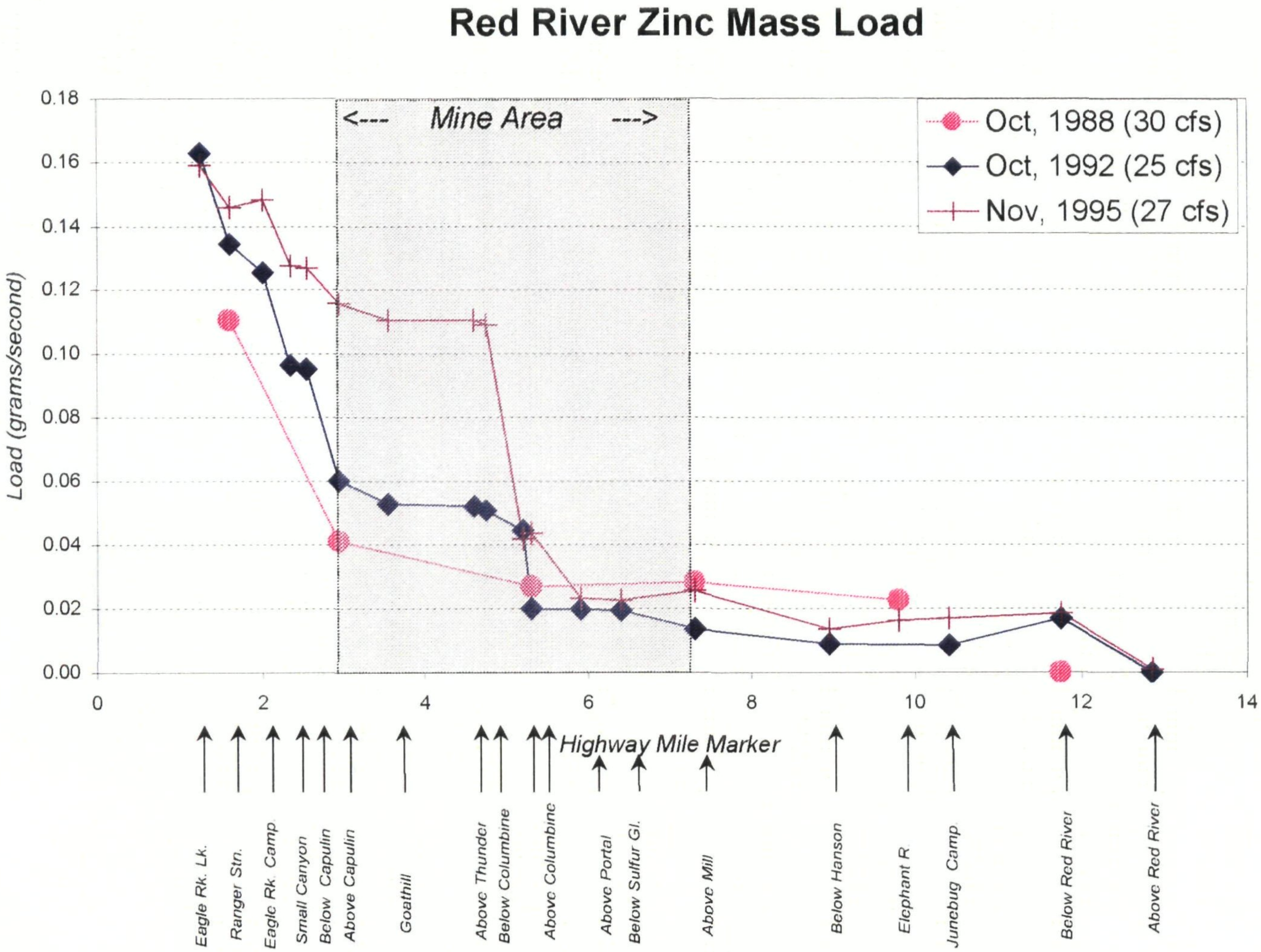


Figure 9. Zinc mass load in the Red River for several dates of measurement (1965 to 1995).

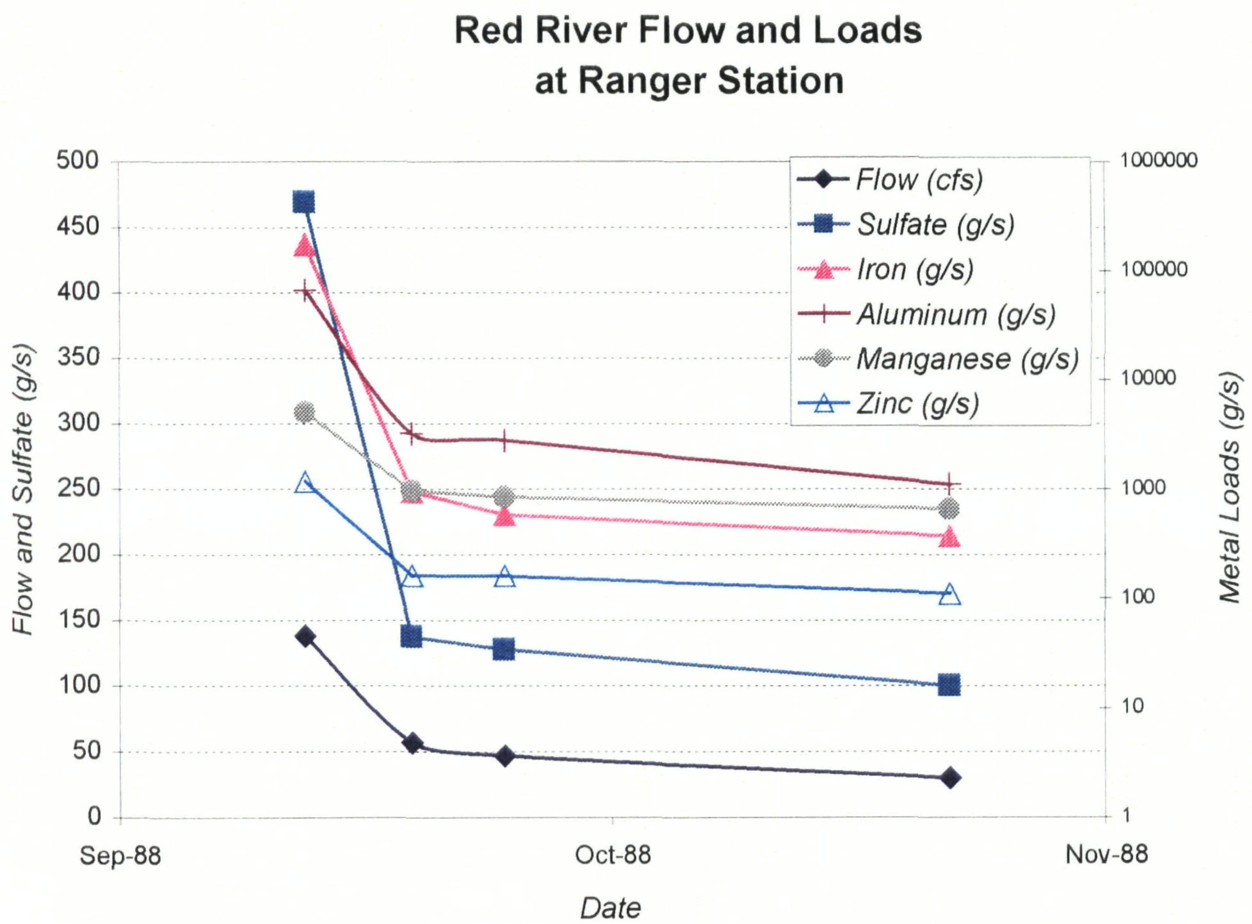


Figure 10. Mass loads in the Red River at the USGS station near Questa for several September and October, 1988.

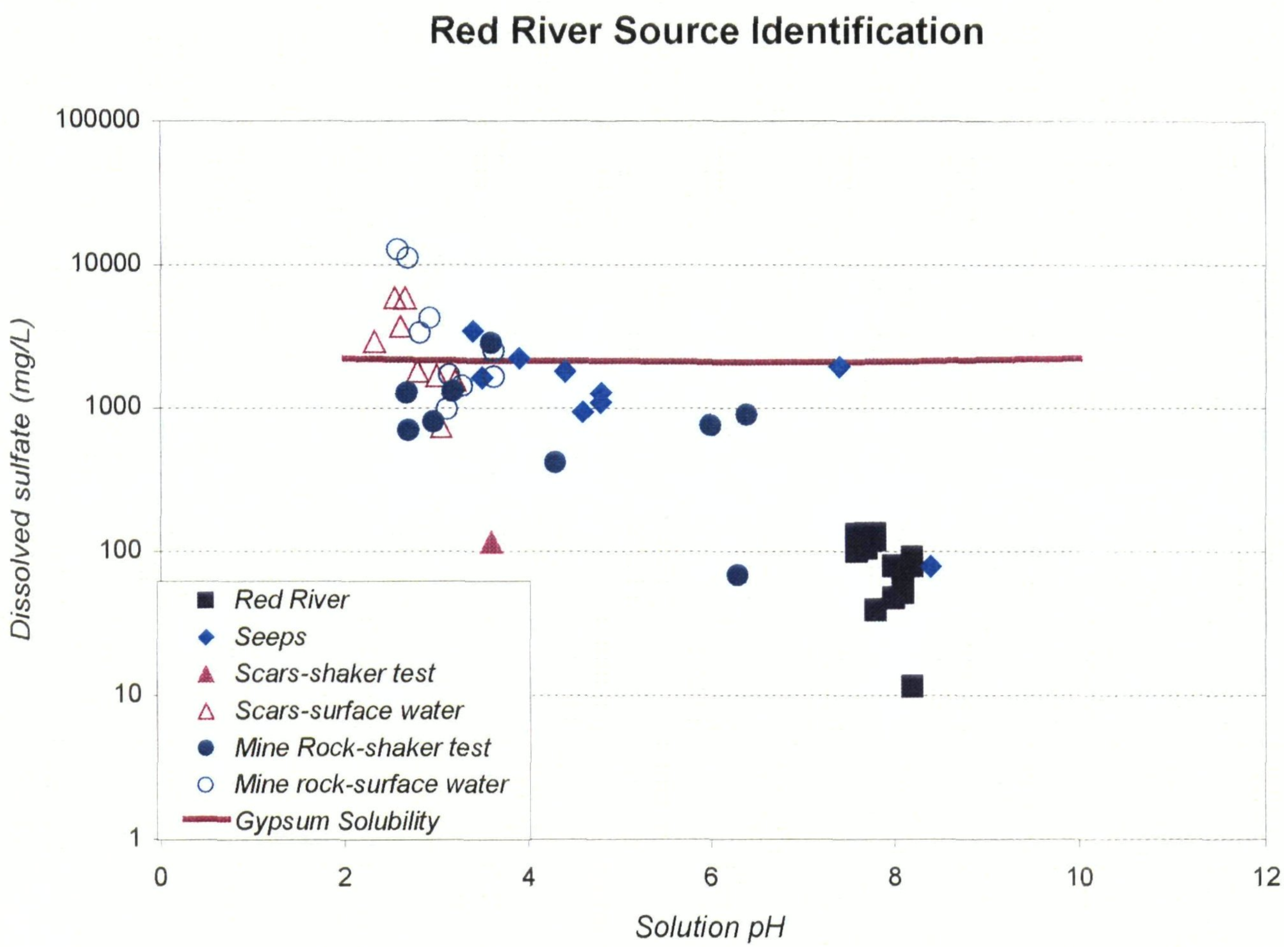


Figure 11. Concentration of sulfate in the Red River, seeps, and in potential sources.

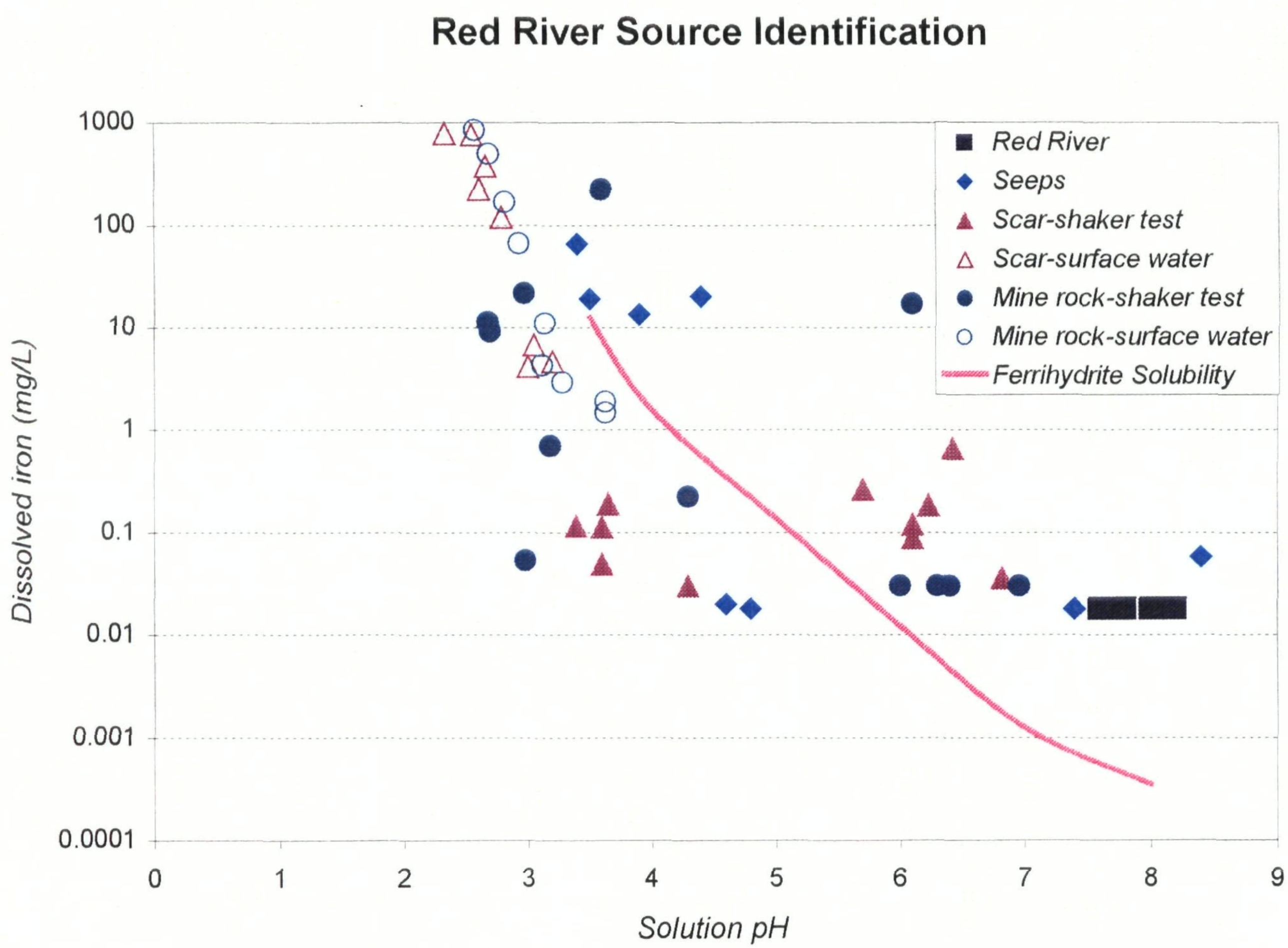


Figure 13. Concentration of iron in the Red River, seeps, and in potential sources.

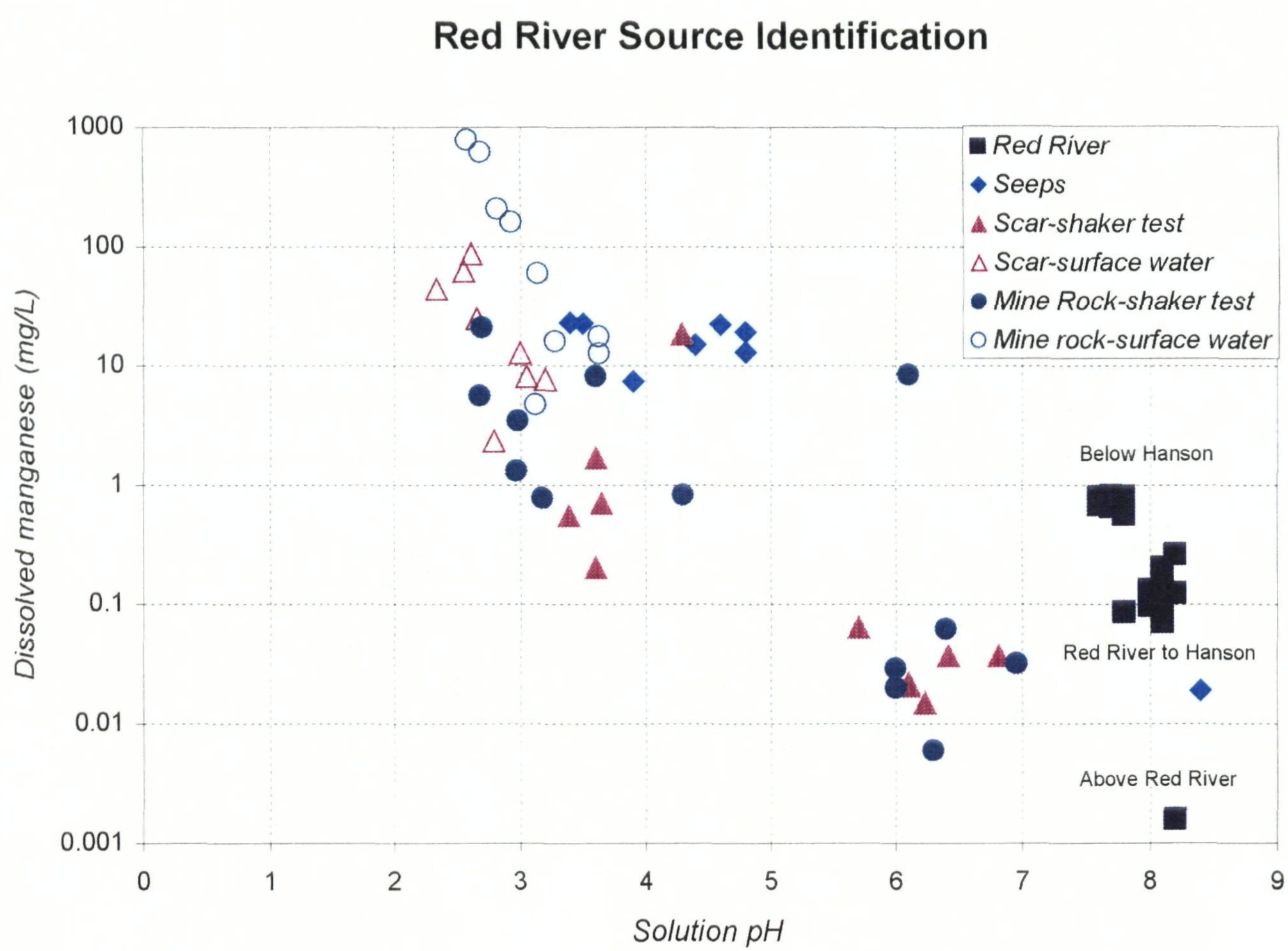


Figure 14. Concentration of manganese in the Red River, seeps, and in potential sources.

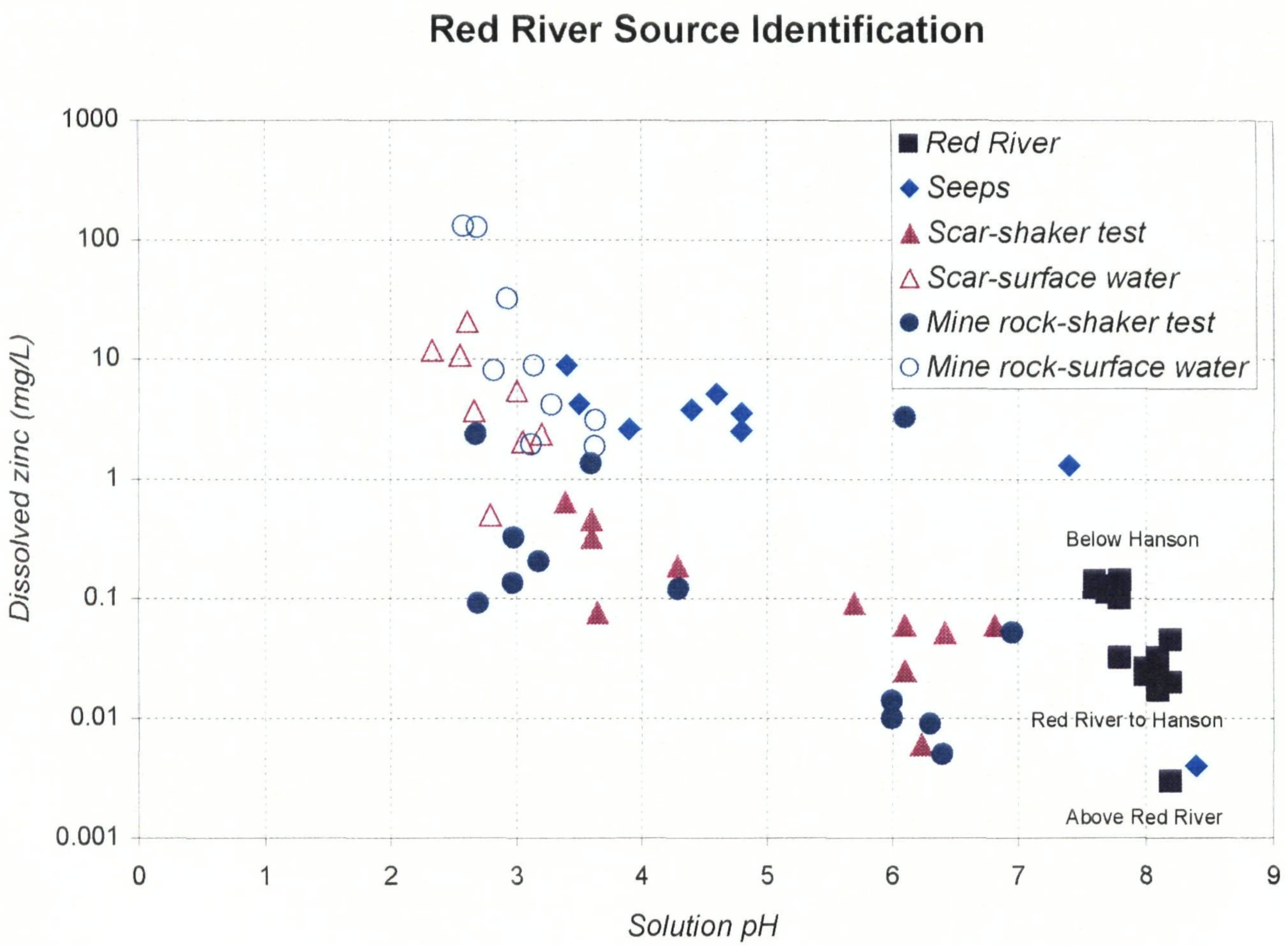


Figure 15. Concentration of zinc in the Red River, seeps, and in potential sources.

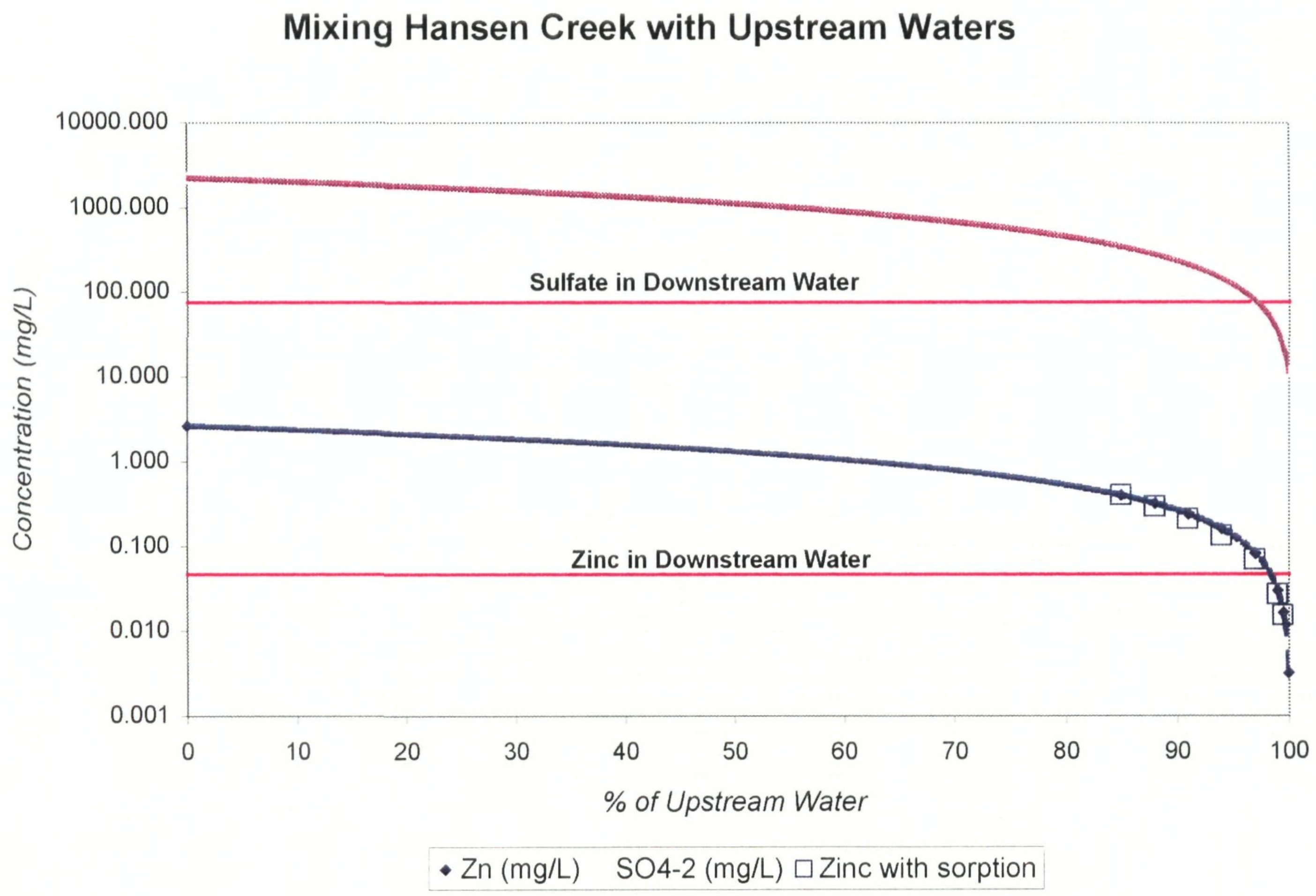


Figure 16. Model of various mixtures of Red River water above Hanson Creek with acidic Hanson Creek water as compared with downstream water.

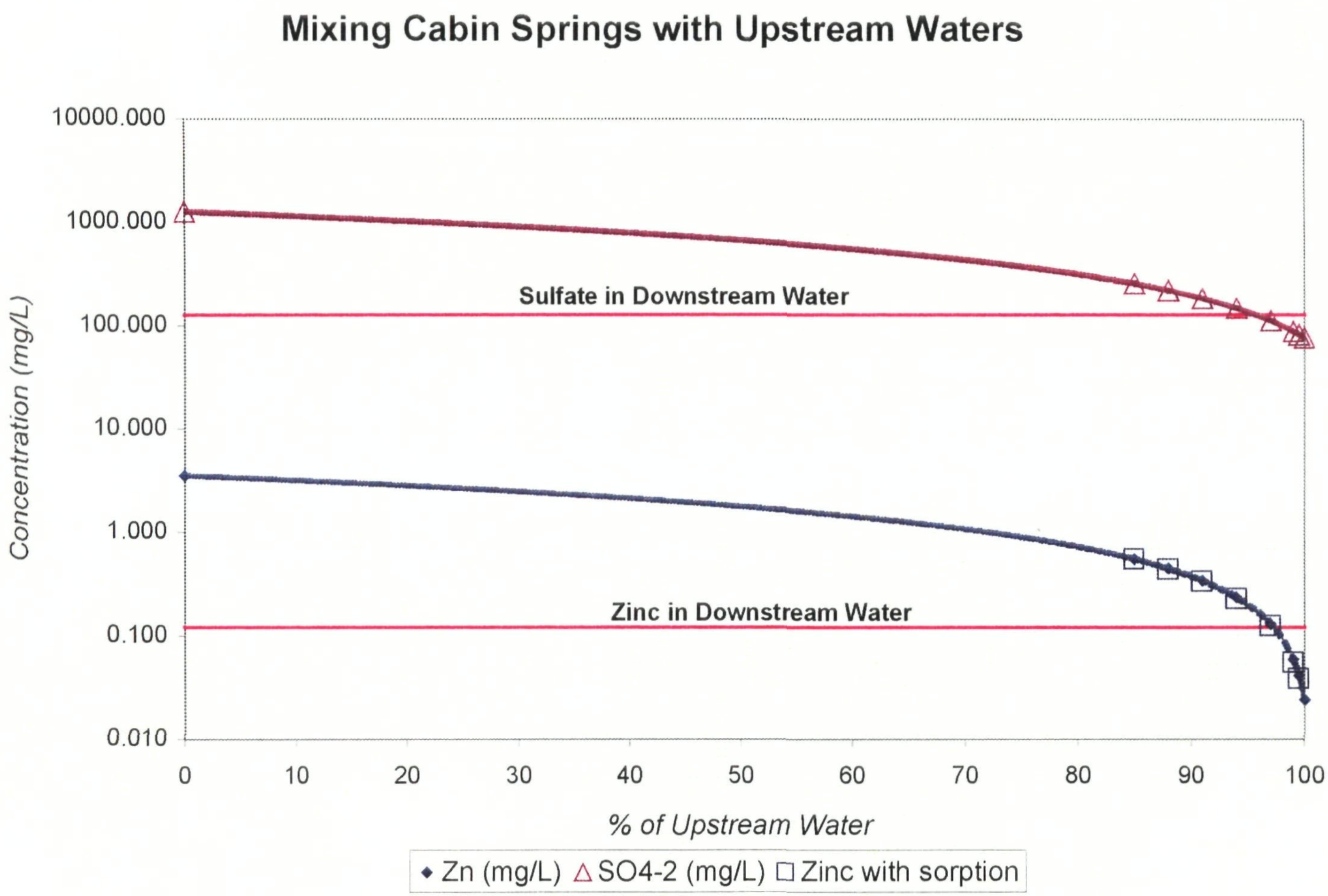


Figure 17. Model of various mixtures of Red River water above Hanson Creek with Cabin Springs water as compared with downstream water.

Resume

William M. Schafer

Resume

Dr. William M. Schafer

Schafer & Associates
865 Technology Blvd,
P.O Box 6186
Bozeman, MT 59715
(406) 587-3478
(406) 587-0331 (Fax)
bschafer@avicom.net

POSITION DESCRIPTION

POSITION: PRINCIPAL - SCHAFER AND ASSOCIATES

Dr. Schafer oversees a multi-disciplinary staff of scientists, engineers, and support staff. He is responsible for technical direction of projects, project team staffing, and office management. Dr. Schafer specializes in soil geochemistry, vadose zone and groundwater hydrology, and mine reclamation.

PROFESSIONAL EXPERIENCE

SCHAFER & ASSOCIATES: 1985 TO PRESENT

Mining Services: Served as project manager or technical director for over 200 projects involving the environmental aspects of mining. Projects have included prediction, prevention, and control of acid rock drainage (ARD); mine closure including reclamation of waste rock, tailings, and spent ore piles; decommissioning of spent ore material; baseline studies in support of permit applications; groundwater and vadose zone monitoring programs. Extensive regulatory experience in the western US including Nevada, Montana, South Dakota, Colorado, New Mexico, Idaho, Utah, Washington and Arizona.

Solid and Hazardous Waste: Managed or directed numerous CERCLA investigations including RI/FS activities at several mining sites. Developed and implemented numerous work plans and planning documents to support site characterization, treatability studies, and risk assessments. Responsible for development and evaluation of the performance of in-situ remediation techniques for inorganic mine waste at CERCLA sites. Experienced in conducting fate and transport analysis of migration from a variety of contaminant sources. Conducted numerous field investigations using a variety of field screening techniques including soil gas surveys and X-ray fluorescence determination of soil lead, arsenic, copper, zinc, and chromium levels. Worked on a number of regional landfill sites involving siting, permitting, and groundwater monitoring.

Project Management: Successfully managed over 300 projects in the environmental sciences concerning hazardous waste (under CERCLA, SARA, and RCRA); solid waste landfills; disturbed land reclamation; baseline studies for mine and facility permitting; reclamation of abandoned mines; surface water, groundwater and vadose zone monitoring; soil investigations; contract R&D; delivery of educational short-courses; and services in support of litigation.

Soil Investigations: Conducted a number of soil survey investigations in support of mine permitting and planning, major facility siting, irrigation development, basin-wide erosion prediction and control, and salinity control. Numerous small-scale soil investigations have been performed for on-site waste treatment system siting and design; for land application/ treatment of liquid and solid wastes; litigation support for industrial damage claims; and in support of archaeological investigations.

Expert Testimony: Served as an expert witness for several cases involving the environmental effects of mining; acid-rock drainage; alleged contamination of surface water or groundwater with metals salinity and organic compounds; and Clean Water Act violations. Provided expert reports, sworn testimony, and depositions in lawsuits, and administrative hearings.

EDUCATION

Montana State University *1979 to 1984*
Bozeman, Montana
ASSOCIATE PROFESSOR

Served as an Assistant Professor of Soil Science at Montana State University until 1984. Responsibilities included teaching, extension, and research in reclamation of disturbed areas, land resource management, and dryland and irrigated agriculture. Developed and delivered a number of professional short courses on vadose zone monitoring, cyanide heap leaching, underground storage system installer certification, groundwater impacts of petroleum exploration, control of dryland salinity, fertilization of small grains and forages, and salinity and sodium control under irrigation.

Montana State University *1976 to 1979*
Bozeman, Montana
PH.D. IN SOIL SCIENCE

Dissertation Topic: Completed an evaluation of the land capability of soils on reclaimed surface coal-mined areas throughout the Northern Great Plains.

University of California at Davis *1974 to 1975*
David, California
M.S. IN SOIL SCIENCE

Thesis Topic: Developed a technique to measure the shrink-swell potential of soils in the Central Valley of California, and to predict the hazard for construction.

Colorado State University *1971 to 1974*
Fort Collins, Colorado
B.S. IN WATERSHED SCIENCE

PROFESSIONAL DEVELOPMENT

1984	ON-SITE WASTE SYSTEM DESIGN (UNIV OF WASHINGTON)
1986	UNDERGROUND STORAGE SYSTEMS (NWWA COURSE)
1987	OSHA HEALTH AND SAFETY FOR SUPERFUND WORKERS (40 HOUR)
1988	OSHA HEALTH AND SAFETY FOR SUPERFUND SITE MANAGERS (WEX, 8 HR. COURSE)
1990	OSHA HEALTH AND SAFETY REFRESHER (8-HOUR)
1991	IBM PC APPLICATIONS IN GROUNDWATER POLLUTION AND HYDROLOGY (6-DAY NWWA COURSE)
1991	FIELD X-RAY FLUORESCENCE TRAINING (SPECTRACE INSTRUMENTS, FORT COLLINS, COLORADO)

ORGANIZATIONS

Professional improvement maintained through active involvement in professional societies (ASTM, National Water Well Association, Society of Mining Engineers, Soil Science Society of America). More than 50 articles, papers, and book chapters have been authored in professional publications. and in Symposia Proceedings

PUBLICATIONS

SYMPOSIA PUBLICATIONS

Schafer, W.M., Tom Grady, and Chris Luckay. 1997. Control of Tailings Oxidation Rate Using Tailings Placement Methods. Fourth International Conf. on Acid Mine Drainage

Spotts, E., W.' M. Schafer, T.S. Mitchell and C.F. Luckay. 1997. Decreasing Surface Runoff Metal Loads from Historic Tailings Using In-Situ Liming and Reclamation Techniques. Fourth International Conf. on Acid Mine Drainage

Spotts, E., W.M. Schafer, C.F. Luckay and T.S. Mitchell. 1996. Determination of Runoff Metal Loading from Reclaimed and Unreclaimed Tailings. Colorado State University Tailing and Mine Waste 1997

Spotts, E., W. M. Schafer, C. F. Luckay, and T. S. Mitchell, W. M. Schafer, C. F. Luckay, and T. S. Mitchell. 1996. Determination of runoff metal loading from reclaimed and unreclaimed tailings. Billings Conference

Schafer, W.M., Chris Luckay, Lisa Kirk, Troy Smith, Steve Smith and Fess Foster. 1996. Hydrologic Evaluation of Acid Rock Drainage Controls in a Sulfide-Enriched Waste Rock Pile. Fourth International Symposium on Environmental issues and Waste Management in Energy and Mineral Production

Schafer, W.M., Thomas Grady, Donald D. Runnells, Chris Luckay, and Ric Jones. 1996. Control of Tailings Oxidation Rate Using Spigotting Techniques. Fourth International Symposium on Environmental issues and Waste Management in Energy and Mineral Production. Cagliari, Italy

Spotts, E., W.M. Schafer, T.S. Mitchell and C.F. Luckay. 1996. Effect of IN-SITU Liming and Reclamation at Decreasing Surface Runoff Metal Loads from Clark Fork River Tailings. Colorado State University Tailings and Mine Waste Conference, Febraury, 1997. Fort Collins, CO

David A. King, Christopher F. Luckay, and William M. Schafer. 1996. Monitoring Instrumentation for Assessing ARD Development at Mine Sites SME Annual Meeting and Exhibit

Kirk, L.B., William M. Schafer, James Volberding and Scott Kranz. 1996. Mine Lake Geochemical Predication for the SPJV McDonald Project Billings Symposium pg 393-403

Spotts, E., and William Schafer. 1996. The Use of Kinetic Test Data to Develop Site-Specific Criteria for Acid Generation Potential - An Overview of Results from Several Mines. Whitefish Conference

Schafer, W.M., and Edward Spotts. 1996. Fate and Transport of Metals from Clark Fork River Streamside Tailings. Billings Conference

Schafer, W.M., Todd Duex , Chris Luckay2, and David King2. 1995. Characterization of the Contaminant Potential and Remediation Measures in Waste Rock Piles in the US. Wismut Waste Rock Remediation Workshop, Chemnitz-Siegmar, Germany, November 6-8, 1995.

Schafer, W.M., John G. Goering , Tom R. Grady, Edward Spotts, and Dennis R. Neuman. 1994. Modeling Recharge And Runoff To Predict Copper And Zinc Transport From Lime-Amended Tailings At The Silver Bow Creek Cerlca Site. Billings Conference

Schafer, W.M., Steven Smith, Chris Luckay and Troy Smith. 1994. Monitoring Gaseous And Liquid Flux In Sulfide Waste Rock. Proc. Of the Third Intl Conf of the Abatement of Acidic Drainage., Pittsburgh – April, 1994

Edward Spotts and William M. Schafer. 1994. Determination Of Metal Adsorption Capacity Of Soils For Disposal Of Mining Process Solutions By Land Application, Proc. Of the Third Intl Conf of the Abatement of Acidic Drainage., Pittsburgh – April, 1994

Schafer, W.M. 1993. Lime Neutralization of Acid Mining Waste in the Clark Fork Basin Presented at the Lime Products Tech. & Reclamation Conference, Anaconda, MT

Schafer, W.M., J.G. Goering, T.R. Grady, E. Spotts and D.R. Neuman. 1993. Modeling the Fate and Transport of Metals in Surface Water at the Silver Bow Creek CERCLA Site. Billings Symposium

Steven C . Smith, Thomas J. Hudson and William M. Schafer. 1993. Field Evaluation of Land Application Performance: Metals Removal from Barren Leach Solution. Billings Symposium

Schafer, W.M. 1993. Mitigation of Acid Mining Waste Using Lime Application in the Upper Clark Fork Basin. Presented at the Lime Products Tech. & Reclamation Conference

Schafer, W.M. 1992. Environmental Management for Acid-Forming Mining Waste. Successful Mine Reclamation-What Works. Nevada Mining Association, Reno Nevada

Schafer, W.M. 1992. Acid Rock Drainage: Processes and Prediction Using, Static and Kinetic Testing. 1992 SME Annual Meeting

Schafer, W.M. 1992. Heap Leach Rinsing Principles and Examples. 1992 SME Annual Meeting

Schafer, W.M. 1992. Acid-Forming Mining Waste: Prediction, Control and Treatment. RANDOL Gold Forum Vancouver 1992. Pg 345-353

Spotts, E., T.S. Mitchell, C.T. Hoschouer, and W.M. Schafer. 1992. Evaluation of Organic Substrates for Use in Wetlands Constructed to Treat Acid Mine Drainage. Billings Symposium

Schafer, W.M., and Dirk Van Zyl. 1991. Cyanide Degradation Field Study of Spent Heap-Leach Ore at the Landusky Mine. Heap & Dump Leaching an International Newsletter

Schafer, W.M., D. Van Zyl, J. Goering, and S. Smith. 1991. Cyanide Degradation and Rinsing Behavior in Landusky Heaps (abstract). Presented at the Montana Mining Association, May, 1991, Butte, Montana.

Schafer, W.M. 1991. Sediment Control and Reclamation of Waste Rock and Heap Leach Spent Ore, presented at the Engineering and Environmental Aspects of Mine Waste Disposal Short Course, Society of Mining Engineers, February, 1991, Denver, Colorado.

Schafer, W.M. 1991. *In-Situ* Treatment of Acid Generating Tailings, presented at the Engineering and Environmental Aspects of Mine Waste Disposal Short Course, Society of Mining Engineers, February, 1991, Denver, Colorado.

Schafer, W.M. 1991. Heap Leach Rinsing and Spent Ore Disposal, presented at the Engineering and Environmental Aspects of Mine Waste Disposal Short Course, Society of Mining Engineers, February, 1991, Denver, Colorado.

Van Zyl, Dirk, W.M. Schafer, and Mike Henderson. 1988-1991. Cyanide Heap Leaching Technology Short Course, presented in Butte, Montana; Bend, Oregon; Denver, Colorado; and Reno, Nevada.

Schafer, W.M. and E. Spotts. 1990. Evaluation of Substrate Suitability for Sulfate-Reducing Wetland Systems (abstract). In: National Association of Abandoned Mine Land Programs. September, 1990. Breckenridge, Colorado.

Schafer, W.M. and T.J. Hudson. 1990. Land Application of Cyanide-Containing Mining Processes Solutions. p. I-60-76 In: Fifth Billings Symposium on Disturbed Land Rehabilitation. March, 1990. Billings, Montana.

Schafer, W.M., E. Spotts and T.J. Hudson. 1990. Soil Geochemistry of Lime-Amended Sulfide Mining Waste. p. II-13-34. In: Fifth Billings Symposium on Disturbed Land Rehabilitation. March, 1990. Billings, Montana.

Dollhopf, D.J. and W.M. Schafer. 1990. Montana Abandoned Mine Reclamation Bureau Technical Guidance Manual for Bentonite Mine Reclamation.

Schafer, W.M. 1990. Geochemistry of Amended Sulfide Mine Wastes in the Upper Clark Fork Basin (abstract), presented at the Clark Fork River Symposium, April, 1990, University of Montana, Missoula, Montana.

Schafer, W.M. 1990. Clark Fork Remedial Demonstration Project (poster), presented at the Clark Fork River Symposium, April, 1990, University of Montana, Missoula, Montana.

Schafer, W.M., R.L. Garrison, and D.J. Dollhopf. 1989. Determination of Overburden Suitability by Statistical Analysis of Drillhole Lithologic Data at the WIDCO Centralia Mine, Washington. In: Reclamation: A Global Perspective, Canadian Land Reclamation Association. August, 1989. Calgary, Alberta.

Schafer, W.M. 1988. Implications of Spatial Variability to Postmine Management. p. 231-238 In: Vol. II. Reclamation of Surface Mined Land, L.R. Hossner editor.

Schafer, W.M. 1987. Methods of Determining Vadose Zone Hydraulic Properties (abstract), presented at the Vadose Zone Monitoring Symposium. ASTM. September, 1987. Minneapolis, Minnesota.

Schafer, W.M., M. Babits. 1987. Lime and Tillage Effects on Soil Copper and Zinc Partitioning and Vegetative Response in Acid-Contaminated Agricultural Soils in Southeastern Montana. In: Billings Symposium on Surface Mining and Reclamation (ASSMR). p. J-2-1. March, 1987. Billings, Montana.

Schafer, W.M. 1985. Lime and Tillage Effects on Extractable Metal Levels in an Acid-Contaminated Agricultural Soil. In: Second Annual Meeting - American Society of Surface Mining and Reclamation. October, 1985. Denver, Colorado.

Schafer, W.M. 1985. Proposed Management Techniques for Agricultural Soils Contaminated by Mining Waste (abstract). Montana Academy of Sciences Annual Meeting - Clark Fork Symposium. April 19-20, 1985, Montana Tech., Butte, Montana.

Bauman, B.J. and W.M. Schafer. 1984. Estimating Groundwater Quality Impacts from On-Site Sewage Treatment Systems. In: Proc. of the Fourth National Symposium on Individual and Small-Scale Community Systems. ASAE. December, 1984. New Orleans, LA.

Schafer, W.M. 1984. Managing Minesoil Development for Productive Reclaimed Land. In: Ninth Annual Canadian Land Reclamation Association meeting. August 21-24, 1984, Calgary, Alberta.

Schafer, W.M. 1984. Soil Development and Plant Succession on Minesoils in the Northern Great Plains (poster presentation). National Symposium and Workshop in Reclamation of Abandoned Mined Lands. May 21-24, 1984, Bismarck, North Dakota.

Schafer, W.M. 1984. Minesoil restoration and maturity: a guide for managing minesoil development. p. 172-185. In: Symposium on Surface Coal Mine Reclamation on the Great Plains, Billings, Montana. March 19-21, 1984.

Schafer, W.M. 1982. Changes in land capability class resulting from mining. Proc. Symposium on Surface Mining and Reclamation of Coal Mined Lands in the Northern Great Plains. March 8-9, 1982. Billings, Montana. Soil Conservation Society - Montana Chapter. p. C-1-1.

Schafer, W.M. 1981. Reclamation of mined land: a research perspective. Northwest Mining Association annual meeting. December 1-2, 1981. Spokane, Washington.

Parody, F.E. and W.M. Schafer. 1981. Investigation of Berkeley pit overburden as a medium for plant growth. Proc. Symposium on Surface Mining Hydrology, Sedimentology, and Reclamation. December 7-11, 1981. Lexington, KY p. 385-388.

Schafer, W.M. 1981. Productivity of minesoils and native soils in the Northern Great Plains. Proc. Symposium on Surface Mining Hydrology, Sedimentology, and Reclamation. December 7-11, 1981. Lexington, KY p. 487-492.

Schafer, W.M. 1980. New soils on reclaimed land in the Northern Great Plains. Proc. of Adequate Reclamation of Mined Lands: A Symposium. March 26-27, 1980, Billings, Montana. Soil Conservation Society - Montana Chapter.

Schafer, W.M. and G.A. Nielsen. 1980. Soil development and plant succession on 1- to 50-year-old stripmine spoils in southeastern Montana. p. 541-549. In: M.K. Wali (ed.) Ecology and Coal Resource Development VI. Pergamon Press, NY.

Wyatt, J.W. and W.M. Schafer. 1979. Root abundance and microbial activity in 1- to 50-year old stripmine spoils in southeastern Montana (abstract) ASA annual meetings, August 6-9, 1979, Fort Collins, Colorado.

Jensen, I.B. and W.M. Schafer. 1979. Effect of surface manipulation on percolation, infiltration, and groundwater quality. p. 121-137. In: Proc. Fourth Annual Canadian Land Reclamation Association, Regina, Saskatchewan.

Schafer, W.M. 1979. Cover-soil management in Western surface-mine reclamation. Proc. Symposium on Surface Mining Hydrology, Sedimentology, and Reclamation. December 4-7, 1979, Lexington, KY.

Schafer, W.M. 1979. Spatial variability of minesoils and natural soils in southeastern Montana (abstract) ASA annual meetings, August 6-9, 1979, Fort Collins, Colorado.

Schafer, W.M. and G.A. Nielsen. 1977. Pedologic characteristics of 2- to 50-year old stripmine spoils in southeastern Montana (abstract) ASA annual meetings, November 13-18, 1977, Los Angeles, California.

JOURNAL ARTICLES

Schafer, W.M. and J. Havlena. 1991. Designation D5126-90: Standard guide for comparison of field methods for determining hydraulic conductivity in the vadose zone. ASTM.

Schafer, W.M., R.L. Garrison, and D.J. Dollhopf. 1991 (in press). Determination of overburden suitability by statistical analysis of drillhole lithologic data at the WIDCO Centralia Mine, Washington. International Journal of Surface Mining.

Schafer, W.M. 1984. Agricultural capability of adjacent mined and unmined landscapes in the Northern Great Plains. J. Soils and Water Conservation 39:270-273.

Schafer, W.M., D.J. Dollhopf, D.W. Hedberg, and J.E. Olson. 1983. Water quality and soil water management in western minesoils as influenced by surface manipulation. Reclamation and Revegetation. 2:1-12.

Schafer, W.M. and G.A. Nielsen. 1981. Root biomass calculation using a modified counting technique. J. Range Management. 34:245-247.

Schafer, W.M., G.A. Nielsen, and W.D. Nettleton. 1980. Minesoil genesis and morphology in a spoil chronosequence in Montana. Soil Science Society of America Journal. 44:802-807.

Wyatt, J.W., D.J. Dollhopf, and W.M. Schafer. 1979. Root distribution in 1- to 48-year-old stripmine spoils in southeastern Montana J. Range Management. 33:101-104.

Schafer, W.M. 1979. Guides for estimating cover-soil quality and minesoil capability for use in coal stripmine reclamation in the western U.S. Reclamation Review. 2:67-74.

Schafer, W.M. 1979. Variability of minesoils and natural soils in southeastern Montana. Soil Science Society of America Journal. 43:1207-1212.

Schafer, W.M., G.A. Nielsen, and W.D. Nettleton.. 1979. Morphology of a paralithic contact in a soil over soft sandstone. Soil Science Society of America Journal. 43:383-386.

Schafer, W.M. and M.J. Singer. 1976. A new method of measuring shrink-swell potential using soil pastes. Soil Science Society of America Journal. 40:805-806.

Schafer, W.M. and M.J. Singer. 1976. Influence of physical and mineralogical properties on swelling of soils in Yolo County, California. Soil Science Society of America Journal. 40:557-562

Schafer, W.M. and M.J. Singer. 1976. A reinvestigation of the effect of saran coating on the extensibility of swelling clods. Soil Science. 122:360-364.

OTHER PUBLICATIONS

Schafer, W.M. 1991. Standard D5126-90: Standard guide for comparison of field methods for determining hydraulic conductivity in the Vadose Zone. American Society for Testing and Materials. ASTM.

B.K. Parker, and W.M. Schafer. 1991. Clark Fork River Demonstration Project, Warm Springs, Montana. Draft Final Report submitted to the Office of the Governor, Montana.

Schafer and Associates. 1990. Invitation for Proposal (plans and specifications): Clark Fork River Demonstration Project, Deer Lodge County, for the Office of the Governor, Montana.

Schafer, W.M., D. Van Zyl, J. Goering, S. Smith, and J. Liu. 1990. Cyanide Degradation and Rinsing Behavior in Landusky Heaps. Milestone Report to Zortman Mining, Inc., Montana.

Schafer, W.M. and T.C. Smith. 1989. A mining research contract report - Soil Extractions for Determining Heavy Metal Bioavailability in Mining Waste. Bureau of Mines, United States Department of the Interior.

Schafer, W.M. 1989. Laboratory Evaluation of Beal Mountain Soils for Land Application of Treated Barren Leach Solution. Draft Technical Report prepared for Pegasus Incorporated and Beal Mountain Mining.

Schafer and Associates, Montana State University, CH2M Hill. 1989. Silver Bow Creek RI/FS Streambank Tailings and Revegetative Studies, STARS Phase III: Final Work Plan for Monitoring Treatability Studies. Final Document to Montana Department of Health and Environmental Sciences.

Schafer and Associates, Montana State University, CH2M Hill. 1989. Silver Bow Creek RI/FS Streambank Tailings and Revegetative Studies, STARS Phase III: Field Scale Treatability Study Plot Construction. Final Summary Report to Montana Department of Health and Environmental Sciences.

Schafer and Associates, Montana State University, CH2M Hill. 1989. Silver Bow Creek RI/FS Streambank Tailings and Revegetation Studies, STARS Phase I: Bench-Scale Soil Column and Greenhouse Treatability Studies, and Tailings Ranking System. Final Summary Report, Volume I to Montana Department of Health and Environmental Sciences.

Schafer, W.M. 1988. Forage Establishment in the Upper Deer Lodge Valley. Final Project Report submitted to the Mile High Conservation District, Headwaters RC&D, Butte, Montana.

Schafer, W.M. 1988. Clark Fork River Tailings and Soil Investigation: As Assessment of the Distribution of Mine Waste in the Floodplain, Analysis of Contaminant Migration Pathways, and Discussion of Potential Remedial Measures for the Governors Office, Montana.

Bauman, B.J. and W.M. Schafer. 1983. Permeability of Flathead Basin Soils: Determining Suitability for On-site Waste Disposal. Final Report to EPA, Helena, Montana.

Schafer, W.M. 1982. A guide to oil and gas leasing. Montana Cooperative Extension Bulletin No. 1267. 32 p.

Schafer, W.M. 1982. Saline and sodic soils in Montana. Montana Cooperative Extension Bulletin No. 1272. 55 p.

Schafer, W.M. 1981. SOILSALT Users Manual: A computer assisted decision-making model. Montana Cooperative Extension Bulletin No. 1254.

Schafer, W.M. 1981. Soils and spoils. Western Wildlands 7:28-30.

Schafer, W.M., G.A. Nielsen, D.J. Dollhopf, and K.L. Temple. 1979. Soil genesis, hydrological properties, root characteristics, and microbial activity of 1- to 50-year-old stripmine spoils EPA 600/7-79-100, Cincinnati, Ohio. 212 p.

Schafer, W.M. 1979. Minesoil resources in the Northern Great Plains: Characterization, Evaluation, and Potential. Final Report to EPA Cincinnati, Ohio.

Schafer, W.M. 1978. Minesoil resources in the Northern Great Plains I:1978 Progress Report. Montana Agricultural Experiment Station Research Report 143. 30 p.

Schafer, W.M., G.A. Nielsen, and D.J. Dollhopf. 1977. Soil genesis hydrological properties, and root characteristics of 2- to 53-year-old stripmine spoils. Montana Agricultural Experiment Station Research Report 108. 90 p.